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**Southern Forest
Experiment Station**

New Orleans,
Louisiana

General Technical Report
SO-74

Proceedings of the
Fifth Biennial Southern Silvicultural Research Conference

**Memphis, Tennessee
November 1-3, 1988**

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il·vics \'sil-viks\ *n pl but sing in constr* [NL *silva*] : the study of
the life history, characteristics, and ecology of forest trees esp. in
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sil·vi·cul·ture \'sil-və-,kəl-chər\ *n* [F, fr. L *silva, sylva* forest +
cultura culture] : a phase of forestry dealing with the development
and care of forests — **sil·vi·cul·tur·ist** \,sil-və-'kəlch-(ə-)rəst\ *n*

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Forest Service, forest industry, and university representatives present 4 general session papers giving projections for the 2030 forest and an additional 93 papers dealing with 15 subject areas: atmospheric influences, ecophysiology, seedling production, site preparation, pine regeneration, pine management, hardwood regeneration, hardwood management, vegetation management, growth and yield, forest nutrition, soil-site-stand relations, harvesting-soils, pest management, and wildlife interactions.

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Proceedings of the Fifth Biennial Southern Silvicultural Research Conference

Compiled by
James H. Miller

Memphis, Tennessee
November 1-3, 1988

Sponsored by

Southern Forest Experiment Station

Southeastern Forest Experiment Station

Southern Region of the
National Association of Professional
Forestry Schools and Colleges

Southern Industrial Forestry
Research Council

Silvicultural Working Group--
Society of American Foresters

Hardwood Research Council

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PREFACE

This proceedings documents the research efforts of 226 investigators studying the patterns and processes of managed southern forests through 93 reported studies. These valuable contributions come from formal researchers, extension and staff specialists, and forest managers. The authors represent 18 universities, 7 forestry and horticultural companies, and 5 public agencies, including 5 USDA Forest Service Experiment Stations. Their approaches and findings are worthy of our study and, when appropriate, incorporation into the logical system we call silvicultural literature.

Four invited general session presenters address the upcoming challenges of the 2030 Forest. Future scenarios are projected based on knowledge gained from past studies applied to anticipated problems of the 21st century.

The broadened scope and complexity of the reported studies continue to augment our understanding of southern pine and hardwood culture, including the economics and biological aspects. The role these species play, not just in the southern region, but on the continent and the entire planet, has been recognized. For the first time in this series of conferences, a session on atmospheric influences was added. Reports by several investigators using varied approaches clarified the emerging problem of chronic growth decline in many southern forest types. The general session presenters reinforced this concern. Physiological measurements of trees in vivo were also reported for the first time using developing instrumentation that represents keys to previously locked doors of investigation and understanding.

A field tour to the magnificent Mississippi Delta forests on the third day of the conference was hosted by the Anderson Tully Company. Those who elected to attend expressed appreciation for the opportunity to observe the hardwood management practices used by Anderson Tully in these forests.

Acknowledgments are made to the conference cochairpersons, Gordon D. Lewis and James E. Bell, Southeastern and Southern Forest Experiment Stations, and the steering committee, composed of the following representatives and their sponsoring organizations:

James D. Haywood, Southern Forest Experiment Station,
Alexandria, Louisiana; session coordinator

F. Thomas Lloyd, Southeastern Forest Experiment Station,
Clemson, South Carolina; session coordinator

David L. Loftis, Southeastern Forest Experiment Station,
Asheville, North Carolina; session coordinator

John A. Pitcher, Hardwood Research Council,
Memphis, Tennessee; session coordinator

James M. Guldin, University of Arkansas at Monticello,
Monticello, Arkansas; field tour coordinator

Douglas Frederick, North Carolina State University,
Raleigh, North Carolina

E.C. Burkhardt, Society of American Foresters,
Vicksburg, Mississippi

Ken Gay, Brunswick Pulp Land Company,
Brunswick, Georgia

Bill Gladstone, Weyerhaeuser Company,
Hot Springs, Arkansas

The diligence and thoroughness of planning by these people are to be commended. Special recognition is also given to the superb panel of distinguished moderators that led each session.

Papers published in this proceedings were submitted by the authors in camera-ready form, and authors are responsible for the content and accuracy of their individual papers.

James H. Miller
Program Chairperson
Southern Forest Experiment Station

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General Session
The 2030 Forest

Moderator:

James H. Miller

Southern Forest Experiment Station

THE 2030 FOREST: USDA'S ROLE[1]

George M. Leonard[2]

Abstract.--New types of research are needed to help the South's 2030 forest meet the anticipated demands for its resources. We need research to develop the integrated management systems needed to make forest management attractive to the private land owner in the South. We also need to focus on planting trees today that can withstand whatever climate changes the "global warming" phenomenon may bring.

DEMANDS ON THE 2030 FOREST

The 2030 forest in the South is going to have to meet a wider variety of needs for more people than ever before, and at the same time may be subject to an unprecedented level of climatic stress. The 2030 forest and forest managers face a tremendous challenge. The people here in this room will play the key role in determining whether these forest managers have the necessary tools to meet these challenges.

In 2030, we will live in a nation of 325 million people, and the South will certainly have its fair share or more of that population growth. More people, a shifting mix of economic and ethnic groups, and changing living patterns, all will change how we use our forested lands. Having more people will mean more suburbs, and more people living in rural areas. These people will be concerned about what is happening in the forest around them.

Forests will play an increasingly important role in outdoor recreation. This will put special pressures on public lands, but will also influence how private forests are managed. For many land owners, forest-based recreation, particularly hunting and fishing, will become an important source of income.

We face challenges in providing forage and wildlife habitat in the southern forests of 2030. Total acres of forage in the South will be down, although forage production on forest lands will be up. Deer density will be down. Turkey populations will be down. Even red-cockaded woodpecker populations will be down slightly. It is shifts in land use, not mismanagement, that will lead to these declines. Reversing these trends or preventing them from getting worse will take some work and a better understanding of forest/wildlife interactions.

Fortunately, watersheds are generally in good shape in the South, but problems of nonpoint-source pollution will increasingly affect forest management decisions.

Meeting the demand for timber will be the major challenge to the southern timber industry. You have lost 5 percent of your timberland to other uses here in the South in the last 10 years. The volume of growing stock per acre, while improving, is still below the South's potential. The most recent forest surveys conducted in the South show that net annual timber growth for both softwoods and hardwoods, after rising for decades, has begun to decline. This decline is currently the subject of much study and speculation. The causes have not yet been conclusively determined.

The recent study "The South's Fourth Forest" predicts net growth will rise again, starting in the 1990's for softwoods and after 2010 for hardwoods. Currently, pine plantations account for 13 percent of the softwood inventory in the South. By 2030 this proportion will exceed 50 percent. But if timber removals increase by as much as 25 percent from 1984 levels, as expected, supplies in many areas will be critical. We expect that industrial lands will increase their harvests by more than 60 percent; and, although the contribution from National Forest in this region is relatively small, harvests levels on the National Forest may double. The non-industrial private forest lands are the key, and harvest on these lands will not increase unless we take some kind of action to promote proper harvesting and reforestation.

There are very large opportunities to increase timber growth in the South through regeneration and timber stand improvement activities, mostly on nonindustrial private ownerships. There are also about 8 million acres of highly erodible cropland and 14 million acres of other marginal cropland and pastureland that could yield higher rates of return from growing pine than in their present use. I expect USDA will continue programs designed to assist and provide incentives for improved management on these lands.

---

[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Associate Chief, Forest Service, U.S. Department of Agriculture, P. O. Box 96090, Washington, DC 20090-6090.

RESEARCH NEEDS

Of course, one of the important ways we can meet our timber needs in the South is through research. Since this is a research conference, I suppose I ought to share my views on what research is needed.

We know a lot about the intensive management of trees in the South, particularly the pine species. We have demonstrated the spectacular responses we can achieve with genetic improvement, intensive site preparation, the use of herbicides for release, and precommercial and commercial thinning. We know enough to know that there are additional gains to be made and that we need more research in biotechnology, growth and yield models, regeneration and stocking, and pest management. A glance at the agenda for this conference indicates we have a lot of research going on in these areas, and you are going to learn a lot about that research this week.

I'd like to talk about some areas we aren't spending much time on and suggest that it might be very productive to do so.

There is almost universal agreement that the non-industrial private forest land is the key to meeting the wood supply needs of the southern forest products industry. What do we have to offer to these small landowners? Do we believe the intensive practice of the industrial sector can be applied to these non-industrial private lands? Do we believe that we can convince all these owners that clearcutting, followed by intensive site preparation, is the way to go? Clearcutting might meet the needs of some of these land owners, but I think we are going to have to find non-intensive silvicultural alternatives for many others if we expect them to make their lands part of the region's timber supply. Many of these owners want their lands to have a continued forested appearance. Have we developed unevenaged systems to meet their needs? What about the landowner who wants to raise deer or turkey, as well as timber? Do we have well-developed systems for maintaining mixed pine/hardwood stands?

These same questions need to be answered for many public forest lands as well. For, while these lands furnish only limited quantities of timber in terms of the South as a whole, they are locally important; and clearcutting is not going to be universally accepted just because foresters say that's the best way. We found out on the Monongahela and, within the last month in Oklahoma, that the courts or the Congress will define what's acceptable if we don't. This is not intended to suggest that we are going to quit clearcutting on the National Forests. We won't. It's the optimum silvicultural system in most instances. But we need viable alternatives in visually sensitive and high public use areas.

We need more attention to extensive management systems. We need to better understand our silvicultural systems in the context of the functioning of the entire ecosystem. Public land managers are increasingly finding that it is not enough to know how to grow and harvest trees, or even to integrate silvicultural treatment with game management. The public, or at least significant segments, are becoming increasingly interested in non-game species--witness the red-cockaded woodpecker issue here in the South. When we find the answer on how to meet the needs of the woodpecker, there will be dozens of scarse species of flora and fauna to replace it. Pressures on private lands will also increase.

Finally, there is the changing composition of our atmosphere and the question of what it may portend for our forests. There seems no question that carbon dioxide is increasing in concentration. But there are widely divergent views of where this will lead. Just a few years ago, the theory was that increased pollution would screen out incoming energy and lead to a cooling of the global climate, maybe leading to a new ice age. The current prevailing theory is that the increase in so-called greenhouse gases will lead to global warming. At least we may have the answer bracketed. In any event, we must have a better understanding of the physiological requirements of our forests, so that we can anticipate how they will respond to expected changes. If the theories are right, they suggest the need to look at what species of trees we should be planting and the planned cultural practices, at least in those portions of the range of a species that are near the physiological limits. It doesn't appear that we have much time to get the answers. The unprecedented rate of climate change which is predicted means that the trees we are planting today may mature in climates significantly different than we have today.

One advantage of research in this area is that a good understanding of the physiological characteristics of our trees and forests will be useful in improving regeneration and stand management practices even if we only encounter the normal climate fluctuations we are used to. That understanding will improve our ability to help our forests withstand drought and other stresses and increase reliability of reforestation on marginal sites.

Yes, there are challenges to meeting the demands which will be placed on our forests in 2030. We know many of the answers needed to respond. We must maintain productivity by replanting and managing forests that have been harvested. We must bring more of the non-industrial private lands into the production base, perhaps by giving the owners a greater choice of silvicultural systems. We need to move to the management of entire forest ecosystems, not just the trees or the tree/big game components. And we must understand how our forests and atmosphere interact and develop appropriate strategies for adapting to potential changes. And, as any researcher worth his salt knows, that means that additional research is required.

THE 2030 FOREST: THE INDUSTRIAL DIRECTION[1]

D. M. Crutchfield[2]

Abstract.--The evolution of American forest industry is highlighted by examples from the past. The future of industrial forestry is suggested by continued evolution of technology and need. A series of educational activities are presented as necessary, that should begin soon to assure the future of continued development of forest industry.

Thanks to Jim Miller for asking me to participate in this look: "AT THE 2030 FOREST," along with these distinguished colleagues-

Fellow foresters, ladies and gentlemen:

I am going to lead you to look back at our past - I'm going to look into the future using my crystal ball - and I'm going to talk about concerns that need attention now, to secure the future of the forest industry.

Last June, I was asked to review the progress of American Forestry from the arrival of Europeans, to the early 20th century. And, here today, I'm charged to look 40 years into the future - I was given 10 minutes to cover the first 400 years, and now have just 30 minutes to cover the next 40 years.

Let's look back for a few moments. What I learned from a look back in time, was; that people constantly responded to new markets and emerging technologies to produce needed goods. Here are some examples.

Among the first Europeans to visit these shores was a British Naval Officer. Captain Weymouth, who first described the vastness of the white pine forest of Maine in 1605. He took samples of wood and seeds back to England, where today it is still known as Weymouth pine.

He saw the tall straight white pines as masts for the sailing vessels of the day - all in one piece, and located in a British Colony. At that time England was buying short stems of Scotch pine, from the shores of the Baltic Sea, and piecing together masts for their tall ships.

During the 1700's, the British government began contracting for white pine masts, and a new industry was born. The most suitable trees, straight and of ample diameter[3], were actually reserved from landgrants, and marked with the king's broad arrow blaze, this setting up a reserved timber supply, for this new industry.

In the Carolinas, the first settlers gathered the heartwood of downed longleaf pines, constructed tar kilns, and extracted rosin and pitch from this freely available resource. These naval store products were of great demand for the sailing vessels of the British merchant and naval fleet. To encourage the flow of these needed products, parliament paid a bounty on barrels of pitch and tar from 1705 to 1725.

As these naval stores were collected and shipped in barrels, another forest-based industry was required, that of cooperage. An entire technology evolved to create the different kinds of barrels, casks, kegs, and hogheads of slack or tight cooperage for the transport, storage and shipping of colonial products - including deer skins, indigo, rice and tobacco.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Technical Assistant to the Research Director, Westvaco Corporation, Summerville, SC.

[3] 24 inches and upward in diameter at 12 inches above ground-line.

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Logs and squared timbers were brought to the river banks and made into rafts that were floated down-stream to sawmills driven by water-power. As water power evolved, it was used to operate saws to cut boards from squared timbers, thus permitting a change in construction options from log cabins or posts and beam timbers to now include framing and siding. Credit for the first water powered sawmill is claimed by Maine with authenticated records in 1634, and by Jamestown, Virginia before 1620.

People travelling the dirt roads got tired of mudholes, deep ruts, and other inconveniences, and came up with the idea of plank roads.

The concept was that travelling by wagon or stage would be faster and surer so people would gladly pay to travel a plank road. This was to be a boon to the forest industry as the best oak planks were given a 7-year life, then the entire road would need re-planking. About the time plank road were being built, the steam engine and railroads came along.

Thus, ended one dream, but began another. The new railroad dream - was even better for forest-based industry! It would use both ties for the road and fuelwood for steam!.

The use of the steam engine to power a ship in 1807 - by Robert Fulton, and to power the "best friend", a train locomotive in 1830, opened the evolution of the technology of steam power!

The sustained power of steam engines, replaced horses oxen, not only for transportation but also for logging!

The pace of harvesting the standing forest was increased by using donkey engines, shay locomotives, and other machines designed specifically for harvesting the forest and transporting the logs.

The invention of wood grinding machinery about 1840, permitted the use of white softwoods for pulping and the production of paper, replacing rags as a primary raw material.

About 1935, Dr. Herty in Savannah proved that it was possible to use chemical pulping of second growth southern pine wood for paper-making. Thus, opening the South to the pulp and paper industry.

By recalling these historic incidents in the development of the forest-based industry, I see a pattern where new technologies emerged, providing better methods and new products.

In my opinion - we can be assured that changes in people's needs and product technology will continue into the 21st century and the forest industry will continue to meet these product challenges.

I haven't been around too long, and while I never believe all the heroic feats and ascribed to the giant lumberjack - Paul Bunyan, and his blue ox, Babe - I can remember being scoffed at for predicting the operational application of fertilizer to forests; and I never really believed I would see, with my own eyes, a helicopter forwarding hardwood pulpwood to the deck! But - I have!

So what's ahead for industrial forestry in the future?

When I look into the future in my crystal ball: I see much of the South still about 50% covered with forests.

I see lots of pine plantations, some growing 5 to 6 cords/acre each year with the benefit of intensive culture, plus gains from continued genetic selection: for efficiency in photosynthesis, for high carbon allocation to stems, and for effective nutrient utilization, captured by vegetation propagation and tissue culture methods; or even by genetic engineering.

I see this less variable, more uniform plantation pine wood going into digesters, then the pulp being separated into high and low density components, made into paper sheets, that are reunited into multilayer papers with an amazing array of specialized properties.

I see paper mills continuing to produce a variety of products, from soft absorbent tissues to saturating kraft, to bleached board and coated printing papers.

I see a host of chemical products from pulp mill recovery systems being processed into inks and dyes, extenders and emulsifiers, stickers and spreaders.

I see sawmills producing high quality lumber and timbers to domestic specifications, as well as to metric specs for export to overseas markets.

I see plants manufacturing studs and sills and dimension stock for framing houses and for making trusses, using oriented strand board cores, covered with veneer for strength, stability, and aesthetics.

The picture is gone! The crystal ball clouded over - to assure this bright and cheery picture of the future forest-industry, there are some things we should start doing right now!

So instead of reciting statistics from the Timber Resource Review of the 1950's - about predicted standing timber volumes, acres of forest, growth and drain.

I ask your patience while I share my ideas on urgent forestry needs.

The first idea I call: Who's in charge here?

The southern forest community has created a system of voluntary guidelines called best management practices.

In contrast, seven states[4] have enacted forest practice laws to assure that private landowners are employing socially acceptable forest practices on their own land.

These two approaches are aimed at the same target - that of private landowners and loggers conducting forestry operations in a responsible manner in regard to clean air, clean water, soil conservation, and maintenance of forest productivity.

The voluntary BMP's are preferred by forest industry, as a method of self-regulation. However, for this system to stay in place into the future will require the industry, along with State Forestry Associations, to police themselves. Operators that don't abide by smoke management guidelines, or careful application of herbicides, or proper crossings of streams, or size of clearcuts, or diversity of timber types and age classes, must be told about the BMP's and the need for all forestry operations to abide by them - or even those operations that follow them to the letter will also lose them.

The delicate balance of BMP's and state forest practice regulations are seen more and more frequently, as communities and counties hear proposed rules and ordinances about: no clear-cutting, no log trucks through town, no burning, and no herbicides.

We need to educate each other, the foresters, the loggers, the landowners, about BMP's.

The second idea is: We are all, the government!

Many of us chose forestry as a life's work because we like being outdoors, didn't want to be tied to a desk, and lots of other reasons.

But, lately some of us have to be reading the Federal Register to keep up with the ever-changing rules and regulations and pending legislation that affect our business and our forests.

Our OSHA manuals have enlarged greatly - our MSDS collections are growing - we have hazardous materials plans for ourselves, and local communities. We dug up our fuel tanks, we report regularly on our used oil accumulations.

The EPA even wanted us to get clearance in each county that is home for an endangered plant or animal, before we could apply pesticides, but the U.S. Fish and Wildlife Service didn't have enough personnel to provide the updated maps for compliance. So this matter has been deferred.

I'm hopeful that each forestry business and agency has somebody keeping-up with the changing regulations and laws both at the state and federal levels. If not, then they need to assign someone to that responsibility.

There is one bright spot in the arena, **The Forestry 2000 Task Force** in the U.S. House of Representative. Over 100 representatives have joined this task force to promote..."The Health, Productivity and Environmental Stewardship of America's Forest...", so there are people in government willing to listen.

We have had foresters making statements at congressional budget hearings! Resulting in enhancement of budgets. This was a joint approach of forestry school deans and their organization - NAPFSC, the state foresters, consultants, and industry - through the American Pulpwood Association and the American Forest Council.

Foresters have gotten into the government awareness process - and our involvement can only get more intense - the future of forestry depends on our involvement in governmental processes today!

We need to continue to educate more foresters to government processes.

Foresters have also gotten into the environmental issues arena. Which is part government and part social forestry. The issue of "acid rain" which came to the forefront several years ago, and which now has a broader scope as atmospheric deposition, is of concern to forest industry. In fact, forest industry has initiated its largest cooperative research program ever, with contributions in the millions of dollars, to the National Council on Atmospheric and Stream Improvement. NCASI personnel are teamed with USFS and EPA people in six regional cooperatives, studying the effects of acid rain and ozone on forest tree seedlings.

The forested wetlands is another environmental issue. There are two pending forestry proposals on how to proceed with monitoring and conducting research in these ecosystems. The Clean Water Act is the driver of this concern. Must we forgo the use of this forest resource to assure water quality; or can we find and agree on practices that provide production of both? Many of these bottomland hardwood sites have been cut and cleared for other uses in the past and regenerated into useful, closed-canopy forests. Surely we can find acceptable ways to do so into the 21st century.

Another facet of the environmental arena is the host of societies and organizations actively working for their concerns. One of the challenges to foresters is to find ways to enter the 21st century walking with these environmental groups - maybe not always in agreement - but not always in conflict. At the grass roots level, we already are working together. In fact, we've had personnel who are responsible to manage sites set aside to preserve endangered plants come to us to learn how to prescribe burn! This signals the realization that even these sites are part of a dynamic ecological process and that management is required. The fires at Yellowstone attest to the advisability of managing even the wilderness systems.

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[4] Alaska, California, Idaho, Massachusetts, Nevada, Washington, and Oregon.

Surely, foresters can find ways to share their concern for the forest, and their management expertise, with others who are also concerned for the forest.

My final point I call: Tell it like it is!

The recent publication of USFS Report: The South's Fourth Forest - Alternatives for the Future, represents the input of many people and is a current look at forestry across the South.

It reports that: most southern states are over 50% forested. Forest products are either the first, second, or third most important agricultural crop in the southern states.

The forest products industry is first or second among manufacturing industries in most southern states.

Ninety percent of the forest land across the South is privately owned!

Private non-industrial	122 million acres	- 67%
Forest products industry	42 million acres	- 23%
Public ownership	18 million acres	- 10%
Total	182 million acres	-100%

We foresters need to share these facts with anyone, and everyone we meet. We need to educate the general public!

We need to expand our efforts to get more participation in Tree Farms. This is both an educational and a public relations program. The more landowners who are aware of forestry opportunities, the more voices there are to speak out on issues concerning forestry.

The more Tree Farm signs along the roadsides - the more landowners will ask about the program - we need to educate the forest landowners.

We need to multiply our support of, and interest in, Project Learning Tree. This program is aimed at teachers in our schools. It is a mechanism to weave into regular courses this supplementary curriculum material about forestry and environmental choices.

The program is not available in 46 states and five Canadian provinces. It was designed by educators and provides classroom materials from kindergarten through 12th grade. The program is funded by forest industry through the American Forest Council and has gained many other sponsors and supporters, like State Forestry Commissions and State Departments of Education, and the U. S. Forest Service.

In South Carolina the current-year goal is to hold 38 workshops, training 750 teachers to use the Project Learning Tree materials in their courses during the school year.

Continued support and enlargement of this program to train at least one teacher in every community school system is critical to the future of forestry!

Project Learning Tree will teach our urban children about the natural processes, about environment, and about forestry in an objective learning experience. We must educate the children.

We must maintain the linkage in people's minds that lumber, plywood, paper, cartons, magazines, newspapers, tissue products, furniture, houses, and an array of chemical products came from the forest!

They come from **trees!**

To help each of you remember to do all this educating - I want to teach you a helpful little jingle about trees - that you can hum on your way home.

It's to a tune familiar to many of you - the words go like this:

Trees, Trees, Trees, Trees, a forester grows trees!

Nothing's more rewarding than a forest full of trees!

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THE 2030 FOREST: AN INTEGRATED RESOURCE[1]

R.C. Kellison[2]

Abstract.--The U.S. South will remain a dominant force in wood production and manufacture by 2030 A.D. The trees will be different, of small size and intensively managed, and the manufacturing plants will be different, relatively free from the emission of pollutants and structured to use wood of small size. Genetically engineered trees of indigenous and exotic origin will be making their appearance, but the appearance will be in the absence of prescribed fires and broadcast herbicide sprays. The landscape will include the bottomland hardwoods and the hardwoods of the Southern Appalachians in a preserved status. In the midst of foreign competition for wood and wood products, North America will remain viable because of a stable economy and a stable government.

INTRODUCTION

Of one thing we can be sure: The 2030 Forest will be different from that of today. If for no other reason, it will be different because of people pressure. Biblical history tells us that the Middle East was once well forested. Because of indiscriminate harvesting, burning and grazing, the resource has long since disappeared, and with it the soil has been depleted of its moisture and nutrient-holding capacity even when it has not been displaced. Efforts have been successful to establish man-made forest, but the process in the harsh environment, is slow and costly.

Deforestation is not limited to the Old World; countries like Haiti have pauperized their forests from the demands of uncontrolled population growth. The same is occurring in Sub-Suharan Africa where a burgeoning population is putting extreme pressure on the limited timber resource in a fragile environment supported by an annual rainfall of less than 20 inches.

Pressure on the forest resource is increasingly coming to bear for reasons other than indiscriminate harvesting, burning and grazing. In the United States, Sweden and Australia, for example, environmentalists have worked against clearcutting, chemical site preparation and forest-fire smoke pollution. The clarion call has been for roadless areas and the preservation of forested areas. These withdrawals together with urban sprawl have effectively removed large quantities of timber from harvest. The areas in the United States most affected involve the public lands of Alaska and the West but the effect is being increasingly felt in New England and the Lake States. Even the U.S. South, the "wood-basket" of our country is feeling the pressure. Summer residents of the Southern Appalachians have been effective in shaping forest policy on vistas far removed from their cottages, and policy makers concerned with the nation's clean water, and plant and animal diversity are making inroads on the allowed disturbance of the nation's wetlands.

The plethora of restrictions has significant social value but it does cause one to wonder how long the nation can remain self sufficient in wood production if the practice continues. This essay addresses the production and utilization practices and technologies needed for an integrated resource.

THE SOUTHERN WOOD SUPPLY

Forecasters have continuously shown that the South is running out of wood and the latest forecast, the South's Fourth Forest (U.S.D.A. Forest Service 1986) is no exception. The prediction is that softwood inventories are on the decline, and hardwood inventories will begin to decline soon after the year 2000. The authors of the report assume that net annual timber growth could be increased by 3.2 billion cubic feet a year from more intensive management of timbered land, and that another 2.1 billion cubic feet a year could be realized by converting marginal crop and pasture land to forest land. This amount, enough to supply 9 chemical pulp mills of 1000 daily tons each is more than half of the wood harvested annually in North Carolina.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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That potential aside, I am not of the notion that we are running out of wood. Technology development has a way of allowing use of a resource that was heretofore of limited value, and to extend a resource far beyond its known manufacturing limits. The first example is exemplified by the pulping of aspen (Populus tremuloides and P. grandidentata). Long disdained by kraft pulp mill managers because of its high phenolic compounds, the species have suddenly found favor with the pulping community because of the development of the chemothermomechanical pulping (CTMP) process. Printing and writing grades of paper, some of which are supercalendered and others which are coated are being produced from a number of new mills built to utilize this resource in the Lake States and Canada.

Thermomechanical pulping (TMP) is another relatively new process that is extending the wood supply. Compared to the kraft pulping process, which is the mainstay of the United States' pulping industry, the TMP process gives about 80 percent more pulp yield (from about 50 percent to about 90 percent of the dry weight of wood entering the mill). However, this gain does not come without sacrifice. The high yield pulps invariably contain high amounts of lignin. Upon exposure to the ultraviolet rays of the sun the lignin in bleached papers turns the product yellow, and the process is both more rapid and more intense with increasing amounts of lignin. For certain types of papers, however, color reversion from white to yellow can be tolerated after a few days or even hours. One such product with high lignin content is newspaper. Another way to avert the limitation is to coat the paper either to hide the reversion or to slow its process. The slick, colorful inserts that cause your Sunday newspaper to be weighed in kilograms rather than in pounds are an example of this kind of use.

Technology to extend the wood supply is not restricted to pulp and paper products. Structural plywood which requires the production and use of peeler logs is being replaced by chipboard, the generic name for a family of products that include waferboard and oriented strand board. The advantage of the latter product over the former is that it can be made out of low-value wood such as tops and thinnings, and even mixtures of softwoods and hardwoods. Manufactured at about 40 percent less cost than structural plywood, chipboard is gaining wide acceptance in the building industry. At least four new plants of this family of products are under construction in Georgia, and at least one is operational in almost all other southern states.

Because of urban sprawl and environmental take-aways, the land base for growing timber in the South in 2030 A.D. will be significantly less than it is now, perhaps down to 150 million acres. We will need every bit of research and development at our command to extend the wood supply, and we will need every acre to be producing to its optimum if we are to meet our needs.

I remain confident that we will not run out of wood even by 2030 A.D., but that wood will be from small trees that will be intensively cropped. A few years ago, we were concerned about the high proportion of juvenile wood found in young pine plantations. Today, that wood is actually desired for such products as linerboard because the thin cell walls of the juvenile wood collapse to give improved burst. Burst, strongly correlated to edgewise compression which is a measure of resistance to crush when filled boxes are stacked atop one another, is now-a-days more desired than tear in all brown papers except for sacks. Better reprographic features are also a characteristic of papers with improved burst.

As for pulp and paper products, solid wood products will increasingly be made from reconstituted wood. That wood will come from small trees, obviating the need for growing sawtimber. The sawtimber that will be grown will command a premium price and it will be processed into premium products. The majority of structural lumber inclusive of that in laminated beams, however, will be from reconstituted wood.

SILVICULTURAL IMPLICATIONS

To meet the wood needs of the next half century, we will be practicing high intensity forestry on the best sites, especially on those lands nearest the processing plants. However, that intensity will be without the use of fire for fuel reduction and site preparation, and it will be without broadcast sprays of herbicides. This loss will be regrettable to the silviculturist but the liability from a burgeoning population that will inevitably invade the forest from urban sprawl will be too great to risk. In their place, will be clean harvests which will greatly reduce site preparation costs, and prescription fertilizers and herbicides that will be applied only to the plants in single formulations.

The genetic material to be used will be a product of molecular genetics and tissue culture. Even without the "green house effect" which I doubt will progress more than at present, plants will be genetically engineered to tolerate droughty conditions, cold tolerance and disease. They will also be genetically engineered to aid in processing, such as reduced amounts of lignin and higher cellulose content. Such alterations will make the forest more subject to attack by pests but, as with agricultural crops, the breeding, genetic engineering and silvicultural practices will be great enough to offset the pests except at the local level.

One of the greatest changes to the forest landscape will be the introduction of fast-growing exotics from the Subtropics, and the use of fast-growing interspecific hybrids. These changes will again not come about by significant changes in the environment; they will excel because of alterations at the gene level.

WHAT OF FOREIGN COMPETITION?

The prognostications about the forestry scene in the U.S. South in 2030 A.D. are partly based on a view of foreign competition. It is becoming abundantly clear that countries in the Tropics and Subtropics, especially those in the Southern Hemisphere, can grow more timber, of better quality, in a shorter time, and at a cheaper cost than we can. Added to that advantage is a higher land base free of a high canopy forest, and a huge, inexpensive labor force. Growth from hardwoods, mostly Eucalyptus spp., Gmelina arborea and Acacia spp. and conifers, mostly Pinus spp. are two to five times greater than on the best sites in the U.S. South. At rotations of 5 to 7 years for the hardwoods, and 16 to 18 years for the conifers, timber shortages, with any kind of planning, can be averted.

Will we in the southern United States be able to compete with our offshore neighbors? The answer is yes, for the foreseeable future. One reason for the positive response is that the mills producing paper, paperboard, and solid wood, are much better horizontally integrated than are the mills in the Tropics and Subtropics. This advantage is especially obvious during financial recessions when foreign sales for items like market pulp, linerboard and lumber are depressed. The market within the United States is large enough to pretty well accommodate mill output, whereas non-integrated mills in the Tropics and Subtropics have to operate at a very low or negative rate of return. The exception to this scenario is when the value of the U.S. dollar strengthens significantly against foreign currencies such as it did in 1982-85. During that period it was cheaper for the U.S. manufacturer to buy pulp, paper, paperboard, and lumber offshore than to buy it domestically. However the lesson learned in fiscal policy by the Federal Reserve Board will probably prevent that event from an early reoccurrence.

SUMMARY AND CONCLUSIONS

Forestry in the southern United States will be greatly different in 2030 A.D. than it is today. The land base for growing timber will be reduced to about 150 million acres, from about 185 million acres in 1988. Those lands, especially those nearest the processing plants, will be intensively cropped, inclusive of prescription fertilizers and herbicides.

Genetically engineered trees with desired wood properties and resistance to pests will be making their appearance. Harvest ages for plantation-grown species for both softwoods and hardwoods will be less than 20 years. The manufacturing facilities will use small trees for fiber and chip products, and perhaps even for substitutes for petroleum products.

Sawtimber, as we know it today, will not be grown except by chance. A premium will be paid for the small amount of sawtimber available, and the wood will be used for quality products; structural lumber inclusive of laminated beams will be from reconstituted wood which has better strength and resiliency than does solid wood replete with knots.

Environmental concerns will play a strong part in how the southern forest is managed in 2030 A.D. We will probably be without the use of prescribed fire and broadcast herbicide spray because of urban sprawl, and the bottomland hardwoods and the hardwoods of the Southern Appalachian Mountains will be preserved for wildlife, recreation, water and aesthetics.

Foreign competition will erode offshore sales of pulp, paper, paperboard and lumber, but the market from within North America will be great enough to keep the wood industry viable. Foreign competition will also vie for the North American market, but we will perservere because of a stable government and a stable economy.

THE 2030 FOREST: DIRECTIONS OF SILVICULTURAL RESEARCH [1]

Chadwick Dearing Oliver [2]

Abstract.—Silvicultural is based on knowledge or forest stand dynamics and silvicultural engineering. Research emphasis is needed in stand dynamics so foresters can make accurate predictions of growth and development of single and mixed species stands, to maintain forest health, and to manipulate forest structures efficiently for a variety of objectives. This research will integrate past research in physiology, genetics, and other fundamental disciplines. After development patterns are understood, case-specific techniques for manipulation can be developed through silvicultural engineering.

INTRODUCTION

When discussing future silvicultural research needs, it is important to look at past successes and failures to determine where foresters have been effective and where more emphasis is needed. A quick look at past forestry practices shows foresters very successful in early years in recognizing broad trends of forest development over landscapes. They then took specific actions to enable the stands to grow in ways helpful to society. Early protecting of forests from fires, erosion, and grazing; planting trees on marginal farmland; and forest practice laws requiring seed trees have led to many stands which comprise our present forest wealth. These successful efforts avoided depletion of our forests and provided a plentiful, continuing supply of inexpensive wood for paper, construction, and fuel. The renewed abundance of forests have allowed us to become concerned with other uses of forests--such as wildlife habitat, recreation, and wetland protection. More recent successes have been in specific, narrower areas of research such as genetic improvement of species for plantations, physiological improvement of seedlings, development of herbicide weed control techniques, and refining soil conditions.

Failures in recent years have been in not anticipating when forests were becoming unhealthy and susceptible to insects, diseases, and fires. Consequently, we have had increases in fires and deaths from insects in recent years in many areas. Similarly, researchers had done so little on how forests developed that they could not respond effectively to the clearcutting controversy--how do the forests develop naturally ? How do we manage the stands on an uneven-aged basis if we choose to ? The lack of wood quality in young plantations in many regions results from a failure to study the effects of stands developing in very uniform spacings and ages. Many mixed hardwood stands in the South and Northeast and mixed conifer stands in the Rocky Mountains are the result of inappropriate high grade cutting; yet research has not studied the stand development patterns enough to determine many other ways to manipulate these stands. The abundance of wood has led to an increased demand for other uses of the forest--wildlife, recreation, wilderness, for example--which require forests of modified structures. Unfortunately, little research has been done to determine how to grow forests for these objectives.

Early successes were anticipating how forests develop and avoiding problems before they occurred; however, there has been a trend away from this overview toward more narrow problems, at the expense of maintaining an integrated perspective of how forests develop. Recent failures, on the other hand, have been where foresters failed to understand and anticipate how forests were going to develop. Although this paper concentrates on the South, similar shifts of emphasis away from an integrated view of forestry--with concommitant failures--have occurred in all parts of the United States.

Future silvicultural research needs an integrated focus on understanding how forests develop and respond to natural and human forces. With this understanding foresters can develop appropriate techniques to protect and manipulate them for many uses.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Research drives many forestry ideas, how foresters are educated, and how they think. Once on a job--be it practice or research--immediate tasks often keep the forester thinking in the same patterns.

This paper will describe what is meant by an integrated focus, how foresters have gotten away from this integrated focus, why this focus is needed, and how it can be achieved.

SILVICULTURE

Silviculture--the manipulation of forest stands to achieve specific objectives--does not exist in isolation. It can be viewed as part of a heirarchy of disciplines, or knowledge (figure 1). The more basic, fundamental disciplines--e.g., mathematics--are at the bottom of this heirarchy. Progressively more derived disciplines lie at higher levels in the hierarchy. The fundamental disciplines are used to explain (or give causality) to the more derived ones, while the more derived ones integrate several fundamental ones.

Within this hierarchy, silviculture rests below the disciplines of forest management and land use. It feeds information to these disciplines. On the other hand, it relies on knowledge of Stand Development and Silvicultural Engineering, which in turn rest on more fundamental disciplines of plant physiology, soils, genetics, statistics, fire behavior, sociology, mechanical engineering, and others. As any discipline, it is important to understand the basic and integrating disciplines below and above a chosen field; however, understanding more basic disciplines--e.g., physiology--does not automatically mean expertise in more integrated ones. For example, a physiologist is not necessarily a silviculturist,nor visa versa, although each may have some knowledge of the other's field.

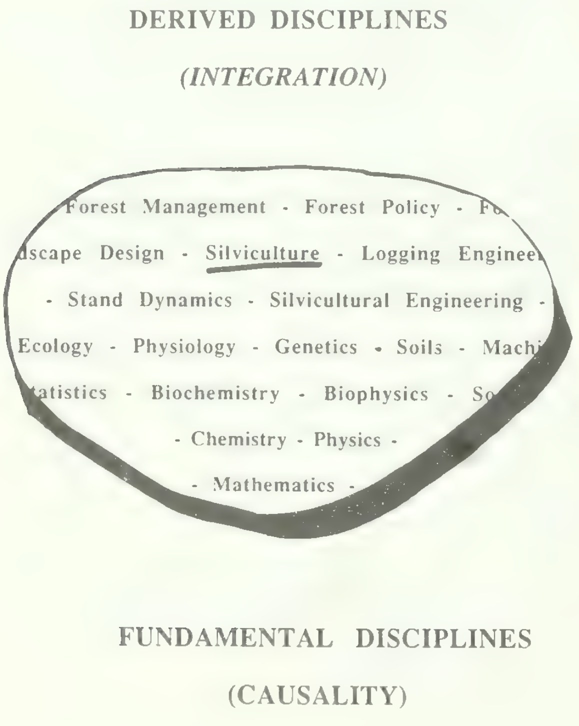
DERIVED DISCIPLINES
(INTEGRATION)
Forest Management - Forest Policy - Fo
dscape Design - Silviculture - Logging Enginee
- Stand Dynamics - Silvicultural Engineering -
Ecology - Physiology - Genetics - Soils - Machi
tatistics - Biochemistry - Biophysics - So
- Chemistry - Physics -
- Mathematics -
FUNDAMENTAL DISCIPLINES
(CAUSALITY)

Figure 1.--Silviculture exists in a heirarchy of disciplines. Through stand dynamics and silvicultural engineering, it integrates more basic disciplines for use in management.

It is important to recognize what knowledge encompasses the field of silviculture. Knowledge in these areas separates silviculture from other, but also important, disciplines. It is only as knowledge increases in stand development and silvicultural engineering that silviculture will serve society and not allow the failures described above.

Forest Stand Dynamics

STAND DYNAMICS refers to the development, structure, growth and yield, and response of stands to natural disturbances and human manipulations. Through understanding stand dynamics, a silviculturists should be able to look at a stand and diagnose it--understand its history and future development with and without various manipulations. This understanding goes beyond simply measuring basal area or projecting board or cubic feet yields, which often mask much of the subtleties of structure. It incorporates subtleties of how individual trees interact, and how the subtleties produce various stand patterns. Understanding the development patterns can help in both mixed and pure species stands.

The Dynamics of Mixed Species Stands.--About two thirds of the southern forests of the next four decades will be mixed hardwood or hardwood/pine stands (USDA Forest Service 1988; figure 2). The mixture of species has led many forest managers to avoid the stands as being too unpredictable and complicated to be manipulated. One

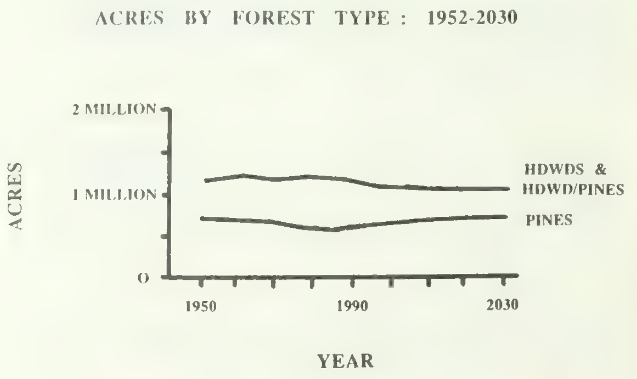

Figure 2.--About two thirds of the South's forests are and will be in hardwoods and hardwood/pine mixtures. About one third, pines.

suggested way to manipulate these stands is by converting them to plantations of pines or single species hardwoods (U.S.D.A. Forest Service 1982). This extensive conversion simply will not occur; in 1978, the south was seeding or planting less than one percent of the total forest land annually (Oliver 1986). The rest of the harvested land has been regrowing naturally--to mixed species hardwoods and hardwood-pines. Foresters will have to learn how to manipulate these mixed stands or over half of the forests will not be manipulated. Once foresters understand the development patterns of these stands, they are proving quite easy to manipulate, quite predictable in growth patterns, and often more efficient to grow than pure species stands. As examples:

--There are predictable patterns to which species dominate in mixed stands on a given site. By understanding the development patterns--which species will overtop others, at what spacings, and on what sites--desired species can be grown with subtle, inexpensive manipulations. For example, cherrybark, water, and willow oaks grow above sweetgums after the first few decades when grown together on river bottom sites (figure 3; Clatterbuck et al. 1985, Clatterbuck and Hodges 1988, Johnson and Krinard 1988). In fact, the sweetgums act as "trainer" trees and keep the oaks well pruned, but allow the oak crowns to expand above the gums and grow to large sizes. Rather than eliminate all sweetgums and establish 1,000 oak seedlings per acre when trying to grow these oaks, about 150 vigorous oak seedlings intermixed with sweetgums can adequately produce an oak stand--without the need for more costly efforts. Water and white oaks have similarly been found to grow above blackgum and ironwood (Bowling and Kellison 1983). On the other hand, red oak may not grow above vigorous red maple sprouts in the Smokey Mountains, so it may be necessary to eliminate the maple sprouts when the stand is young--or plan to manage a maple-dominated stand (Beck and Hooper 1986). Similarly, oaks will generally not grow above yellow poplars (O'Hara 1986), pines, or sycamores at close spacings (figure 4; Clatterbuck et al. 1987); however, these species can be grown together at wide spacings if one species is removed before competition between species becomes too severe. If research can determine more such development patterns, the growth of these forests for whatever use--or a variety of wildlife, recreation, and wood product uses as the trees get larger--can be done very predictably and efficiently.

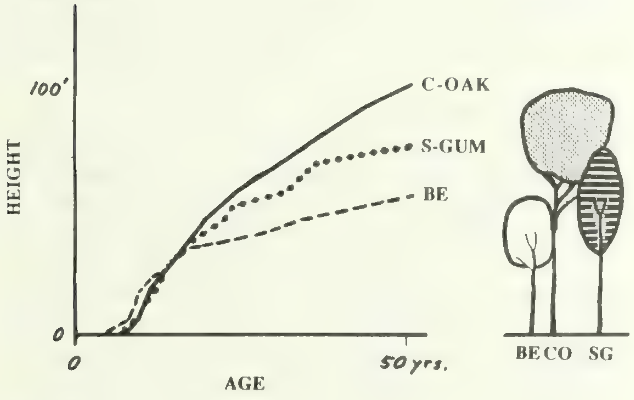

Figure 3.--Through research, mixed stand development patterns can be understood, predicted, and easily managed. On moist, well drained flood plain terraces and natural levees, cherrybark oaks (CO) predictably grow above more numerous sweetgums (SG) and boxelders (BE). This knowledge allows foresters to grow valuable cherrybark oaks without costly planting of pure oak stands or thinnings to remove sweetgum and boxelders (Clatterbuck et al. 1985, Clatterbuck and Hodges 1988).

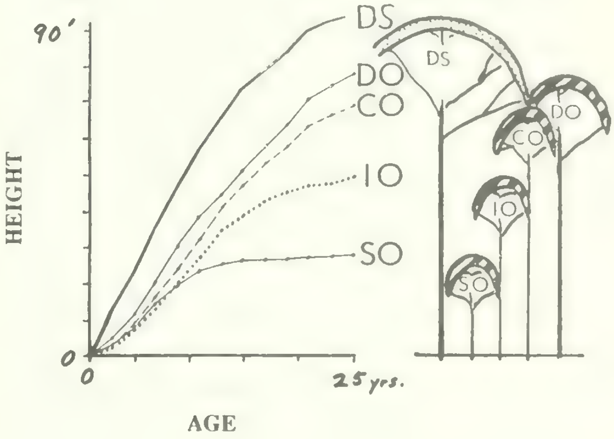

Figure 4.--Research is needed to understand the development patterns of many species, sites, and regeneration mechanisms. Unlike sweetgum and boxelder, sycamore (DS) is not soon outgrown by cherrybark oaks. It dominates the young oaks at close spacings. (SO=suppressed oak at closest spacing to sycamore; IO=intermediate oak; CO=codominant oak; DO=dominant oak, at farthest distance from sycamore) To grow cherrybark oaks the sycamores should be eliminated or spaced widely from the crop oaks and removed at an intermediate harvest (Clatterbuck et al. 1987).

--These mixed, even-aged stands often arose after agricultural abandonment or previous pine or hardwood clearcutting. In addition to wildlife and recreation benefits, they should provide valuable timber even with minimal or subtle silvicultural treatments. An impending, predictable problem requiring attention is the fate of these stands when next harvested. Unless foresters are cautious, the stands will be highgraded, removing trees of high quality and leaving crooked, suppressed, cull trees of low value. These residual cull trees often do not increase in value and prevent trees of better quality from growing. This pattern has occurred in many parts of the world to mixed species stands in the name of "uneven-age management." To prevent this degradation from occurring again, research must begin now to understand the development and response patterns of these stands and how to maintain the forest health in both even-aged and uneven-aged management.

--Mixed stands--especially with the vertical stratification of species--were often assumed to be all-aged when they were in fact even-aged (Oliver 1980). The reverse-J shape diameter distribution and vertical stratification of species does not necessarily mean the smaller trees are younger and are predestined to take over the stand. Had managers known this long ago, they may not have degraded many stands by trying to force incorrect cutting patterns on them. Uneven-aged silvicultural manipulations can be done; however, we currently do not have enough knowledge to do it correctly and consistently.

The Dynamics of Pure Species Stands.--About one third of the stands in the South are predicted to be pine plantations during the next four decades (USDA Forest Service 1988, Figure 2). Research has learned much about the physiology, genetics, and establishment of southern pines; however, if foresters do not understand the development patterns--the interrelations of initial spacings, competition, differentiation, wood quality, and forest health, the problems of small piece size, hardwood competition, poor wood quality, and insect mortality will continue.

--The pines have been planted at close, regular spacings only to learn that diameter growth slowed before such trees were merchantable. There is a relation between diameter a stand will achieve and spacing; however, this relation has not been calibrated well enough to avoid continually planting to inappropriate spacings. Foresters need to synchronize the initial spacing with efficient ways to thin the stands.

--Most southern pine stands developed on old fields in the first rotation. When regenerating these harvested stands, the significance of advance regeneration hardwoods has often been overlooked. Consequently, foresters have had to deal with severe competition, whereas the problem was completely anticipatable by studying stand development patterns. In fact, the same problem had occurred when trying to regenerate old field white pine stands in New England 50 years earlier (Lutz and Cline 1947).

--In some southern pine stands, all trees grow up together without differentiating; they then become diseased or fall over in ice storms without ever becoming merchantable. Other stands differentiate well; foresters have not developed a clear understanding of how to maintain differentiating stands--and how to avoid ones not differentiating.

--There is currently a problem with wood quality of southern pines. Wood quality is directly related to stand development patterns; and an integrated look at the interrelations of stand development, manipulation patterns, and wood quality needs to be developed.

--Old or weakened southern pine stands sometimes become infected and die from the southern pine beetle (Dendroctonus frontalis), as has been known for a long time. Certain stand development patterns appear to lead to these infestations and death; yet foresters did not know enough to manipulate the stands to avoid the outbreaks of the late 1970's. There has been so little research on stand development that foresters have difficulty prescribing resistant stands or anticipating susceptible stands. In fact, changes in forests that are probably the result of natural development patterns are sometimes attributed to acid rain or site productivity decline.

--If forest managers do not understand the relation between initial spacing, competition, stand differentiation, wood quality, thinning practices, and forest health by integrating the fundamental disciplines into an understanding of forest development, they will continue to make our past mistakes with southern pine management.

--Elsewhere in the country there is a similar need for stand development research. The fires in Yellowstone, the Black Hills, and elsewhere and insect outbreaks of past decades in the Colorado Front Range could have been prevented if the development patterns of these stands had been studied sooner. Similar insect outbreaks and uncontrolled fires will occur in the Ponderosa pine forests on the Coconino Plateau south of the Grand Canyon in the next few decades unless the stand development patterns are altered. The regeneration and brush competition difficulties of the young spruce/fir forests of Maine--which led to herbicide controversies--were avoidable had foresters paid closer attention to the development patterns of these stands.

Silvicultural Engineering

If forest stand development patterns become better understood, future problems can be resolved and opportunities seized for manipulating these stands for a variety of objectives. Silviculturists can then tailor specific techniques-- SILVICULTURAL ENGINEERING--based on these stand development patterns, the labor and machinery, economics, and other influences of the given time. It is important, that we UNDERSTAND and ANTICIPATE the development patterns, so we can anticipate and plan for the various techniques, rather than simply REACT TO an unanticipated event. The translation between understanding stand development and applying silvicultural engineering can be through "diagnostic criteria" of tree vigor, stand stability and density, advance regeneration vigor, and others; through decision trees or guides utilizing dichotomous keys or artificial intelligence guides; through computer models of forest development; and through landscape techniques and geographic information systems. Each of these techniques has its strengths and limitations.

Used together, they provide powerful, vigorous tools for interpreting and prescribing stand development patterns.

THE CURRENT STATUS OF SILVICULTURAL RESEARCH

Long ago, forest researchers did excellent research in understanding stand development patterns; however, as early as 1929, they recognized the need for more fundamental research--on seedling growth, for example--and fundamental research was emphasized (Bailey and Spoehr 1929). This research has gained much knowledge in the fundamental disciplines, and it is now time to recognize the need to focus again on more integrated approaches.

Research in stand dynamics is necessary from both a pure and an applied perspective. Much of the research investment in tree physiology, soils, genetics, and similar fundamental disciplines is lost unless it is integrated into an understanding of forest development patterns. By integrating the more fundamental disciplines, it provides a means of verifying the various findings. At the same time, it provides a fundamental level of causality to more integrative research in such pure areas as landscape ecology.

From an applied perspective, an understanding of stand dynamics would have allowed us to anticipate and avoid the problems of forest health and the inefficiencies of manipulating our stands described above. Research in this field is needed to enable foresters to manipulate stands for a variety of objectives--wildlife habitat, stream and watershed protection, aesthetics, forest health, as well as timber production. Research on forest development patterns will make forest changes more predictable, more easily and economically manipulated, and yields more predictable where timber management is the objective.

By concentrating on more fundamental areas, research in silviculture for many years did not keep up with the explosion in knowledge in other areas. Silviculture did not maintain a strong identity by focussing on stand dynamics and silvicultural engineering. Since little research was done in stand dynamics, little progress was made, the discipline of silviculture became poorly defined, and so practically anybody could claim to be a silviculturist. Silviculture research and teaching positions began being filled with people who did research in other areas and, "incidentally," taught silviculture. Such "hyphenated silviculturists"--silviculture-soils, silviculture-physiology, etc.--have not maintained a focus on silviculture at their institution; and research in silviculture has lagged further behind.

Recently, modern, rigorous research techniques in stand dynamics are again being developed. In the past, research papers about stand development patterns were not understood by reviewers of scientific journals more familiar with physiology and mensuration. Consequently, research papers in stand dynamics were not easily accepted in refereed journals. Recently, forest development research is again being recognized and it is becoming easier to have papers accepted for publication in this area (Oliver 1982).

RESEARCH TECHNIQUE NEEDS FOR THE FUTURE

What research techniques are needed for the future ? Forestry research has been very aggressive in incorporating new techniques while maintaining its scientific rigor. Statistics, computer modelling, and physiological causality have been successfully incorporated research techniques.

A challenge will be for silvicultural researchers to maintain the objective rigor of forestry research while expanding their research in the direction of stand development. Because of its integrated nature, stand development "research" can easily degenerate to non-tested descriptions of forests which may or may not be accurate. To avoid these, extreme rigor will be needed to ensure objectivity in research; hopefully, this rigor will not be made at the expense of creativity.

Because foresters need to anticipate future development patterns in constantly changing and extremely varied forests, research in stand development needs to be timely, cost effective, rigorous, and addressing the appropriate level of causality (Figure 1). Some techniques useful to stand development research already exist and are being used: reconstruction techniques, chronosequences, permanent plots, and computer models (Oliver 1982). Each of these has advantages and limitations. Single research studies rarely establish new concepts or breakthroughs in research; rather, several studies done with slightly different techniques are usually necessary to gain acceptance of an idea. Used together, the research techniques described above produce a quite effective means of understanding forest development.

Future research in forest development will probably refine the above techniques as well as develop new ones. One very promising technique is to work with operational foresters in on- line operations. Such operations allow use of a real advantage to silvicultural research--the ability to test hypotheses about manipulations to forests. Working with foresters will involve adaptation and refinement of "production line" research techniques and statistical tests, including "quality control" techniques to test for variations. Such research techniques will have advantages in cost effectiveness as well as support, feedback, and information transfer to the practitioners.

SILVICULTURAL RESEARCH NEEDS

What is needed to ensure silvicultural research proceeds at an adequate rate to ensure healthy, useful forests for a variety of objectives ?

The first necessity is to recognize the importance of stand dynamics and silvicultural engineering as foci of study.

The second necessity is an adequate amount of research being done in stand dynamics and silvicultural engineering. There needs to be a constant focus of one or several faculty on these subjects at forestry research and teaching institutions. With constant, focused attention on these disciplines by knowledgable, creative scientists, new ideas and techniques for researching these subjects will emerge--just as they emerged in more fundamental disciplines when efforts were focused there. Recent research has been making progress in understanding forest development patterns. The information is rapidly increasing and the efforts need to continue.

Thirdly, an adequate amount of research money needs to be focused at the integrated, stand development level to allow scientists to do research there and to keep them from being diverted to other fields. The need for funding is especially serious in comparison to the large amount of funding in more fundamental research areas. Research is largely done at universities, especially with the present reduction in U.S.Forest Service research. At most universities, faculty need outside research grants and contracts to maintain viable research programs: fund graduate students, travel to professional and scientific meetings, and conduct experiments. Scientists will often shift their research careers away from areas with little promise of funding to areas of more promise--hence the present emphasis of forestry school scientists toward fundamental research, which is more easily funded through the National Science Foundation, the Environmental Protection Agency, and the Department of Energy.

Traditional funding sources for more integrated forestry research lag dramatically behind funding for more fundamental research. As shown in figure 5, total funds for 1986 from the National Science Foundation for the Biotic Systems and Resources program (including Ecology, Ecosystem Studies, Population Biology, Physiological Ecology, and Systematic Biology; National Science Foundation 1986) was about the equivalent of the combined research funding of the U.S.Forest Service for forest protection, timber management, and grant research (U.S.Department of Agriculture, Forest Service 1987); the McIntire-Stennis programs to forestry colleges (N.A.P.F.S.C. 1986); and forest industry-sponsored research cooperatives (Survey Results 1988). Only a small part of the U.S.Forest Service, McIntire/Stennis, and cooperative funds are directed toward integrated stand development research.

The Biotic Systems and Resources Program of the National Science Foundation has directed much of its research funds toward seeking "causes" of various forest patterns--i.e., physiological research. Recent increases in National Science Foundation research related to tree gaps, dead wood and tree mortality, and effects of animals on forests (and forests on animals) is beginning to shed light on some aspects of stand development patterns.

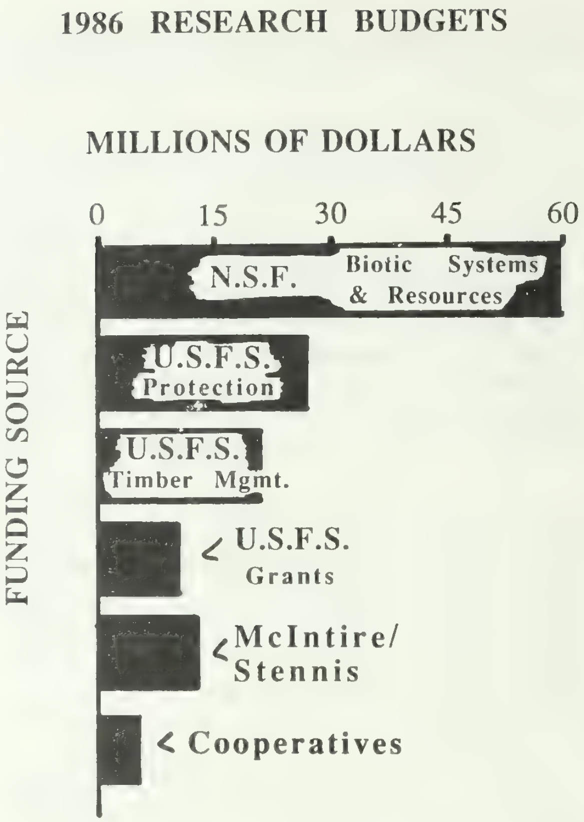

Figure 5. Many traditional sources of funding for forestry research--U.S.Forest Service, McIntire-Stennis funds, Cooperatives--are not large compared to National Science Foundation funding in related fields.

The understanding of how forest stands develop has incorrectly been assumed to be primarily of interest to land management agencies and organizations--forest industry, the U.S. and state Forest Services, and the National Park Service. Consequently, research in stand development patterns has been considered "applied" research to be funded by these agencies and organizations. In fact, knowledge of how forests develop and respond to manipulations is of national concern. Protection of rural homes and forests; provision of habitats for endangered animal species; and protection of streams, wetlands, and fisheries; and provision of jobs as well as wood products are all dependent on our knowledge of how forests grow.

Forest industry has provided little funding for forest development research for two reasons:

--The paper and forest products industry spends little money on research--only 1.0 percent of its sales, compared to 2.3 percent by the manufacturing industries and 9.3 percent by the computer software and services industry (Business Week 1988). Most forest industry research is on product development, not forest growth;

--The forest products industry has considered research on forest development too "pure" to be of immediate interest to them. In fact, research on forest development patterns will make forests more easily and economically manipulated and yields more predictable.

Funds are needed to support scientists at research institutions and graduate students, laboratories, publication costs, and travel to meetings at universities. In this unfortunate cycle in which silviculture finds itself, lack of funding for silvicultural research has resulted in little research and little progress; and the discipline has therefore become poorly defined. Silvicultural positions became filled by people in other disciplines who can obtain funds but did not do research in silviculture or by silviculturists who gravitated to programs with funding; and the cycle continues.

A system needs to be developed to obtain funding in stand dynamics research. Details of the funding need to be developed, but input is needed from forestry colleges and departments within universities, from the U.S.Forest Service and state forestry agencies, from the forest products industries, and from environmental organizations. The funding sources may be directed through the National Science Foundation, through the U.S.Forest Service, directly to Universities, or through other approaches. It is also possible that the new ecological emphasis on landscape ecology and global effects of pollution may look to stand dynamics as an area of "causality," and more stand development research may be supported there.

Once the stand development patterns can be shown to be quite predictable, silvicultural engineering research can be supported both through similar funding and through such present channels as land-owner cooperatives.

TECHNOLOGY TRANSFER

As information develops in stand dynamics and silvicultural engineering, there needs to be an efficient way to relay it to field silviculturists.

Research in silviculture will always need publication in refereed journals; these journals allow other scientists to critique (and thereby maintain the objectivity and rigor of) a scientist's work.

Equally important is contact between the researcher and practicing forester. The dramatic increase in mid-career silviculture training over the last decade shows the desires of the field foresters for more knowledge. Decisions in silviculture are being shifted more to field foresters (Oliver 1986), who are seeking stand-specific information in stand development. Interfacing through symposia and short courses exposes the practicing forester to the latest knowledge and technology.

Many years of experience in a single location are necessary for a silviculturist to understand the subtleties of each forest. At the same time, a silviculturist's abilities increase when exposed to different regions, so the commonalities of stand development processes can be appreciated among many areas. The silviculturist can then relate the patterns to his/her local situation. Maximum success in manipulating forests will probably be if silviculturists are allowed to remain in one place for a long time, but allowed to travel to other areas frequently for professional updating and information transfer.

As silviculture research becomes more sophisticated, it will be more necessary for the researcher to explain his results directly to the practitioner. Interface of the researcher and practicing forester is equally important to the researcher, since it maintains a further source of critiquing of the researcher's ideas and gives ideas for future studies. The necessity of explaining ones research also helps maintain a broad perspective of its relation to silviculture in general.

The importance of the interface and information transfer to practitioners, the benefits of interacting with the practitioners, and the need for detailed explanations should increase the role of information transfer to silviculture researchers. The increased need should be accompanied with an increased respect for the role of information transfer by research and university administrators.

SUMMARY

Silvicultural research in forest stand dynamics is needed to ensure a continuing increase and transfer of knowledge of how stands develop. This stand dynamics research is needed to ensure that much of the pure research is integrated and utilized instead of wasted, and that efforts are not wasted on misinterpreting the causes of various forest structures and growth patterns. Knowledge of stand dynamics, coupled with research on silvicultural engineering, will ensure that foresters have adequate knowledge to protect and manage forests efficiently for the various future uses.

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Atmospheric Influences

Moderator:

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TWENTY-FIVE YEARS OF CLIMATE-RELATED GROWTH TRENDS FOR NATURAL STANDS OF LOBLOLLY PINE IN CENTRAL GEORGIA[1/]

Robert Zahner and Joseph R. Saucier[2/]

Abstract.--A new drought index simulation was used to relate tree-ring widths to variations in summer climate in 38 natural loblolly pine stands along the Piedmont-Coastal Plain Fall Line in central Georgia. A linear aggregate model was used to test the separate effects of site, stand age, stand density, and climate on ring-width variation over the period 1960-1984. Results show that severe summer drought played a significant role in limiting radial growth only once in the 25-year period, in 1980-81. A long period without severe droughts from 1960 through 1979 maintained a generally favorable climate for radial growth. On both Piedmont and Coastal Plain sites there was a significant decline in ring widths over the 25-year period that could not be accounted for by climate[3/].

INTRODUCTION

This paper reports a tree-ring investigation of growth reductions previously documented for the southern pines in the Piedmont and Coastal Plain regions of Georgia (Sheffield and Cost 1987). Dendroecological analysis of forest growth changes related to variations in environment over time require two data components (Fritts and Swetnam 1988): (1) tree-ring chronologies validated for the period of concern, and (2) measurements of environmental conditions as they vary over the period, in this case long-term weather records and field observations of stand and site conditions. The objective was to examine possible causes of suspected radial growth declines in natural stands of loblolly pine (*Pinus taeda* L.) suggested by Sheffield and Cost (1987), in particular the impact over the past 25 years of drought and climate patterns. Lucier (1988) summarizes the key issues in analyzing these pine growth-rate changes including the possible effects of stand density, site conditions, and regional atmospheric deposition.

METHODS

Field Plots

The Forest Inventory and Analysis (FIA) research work unit of the Southeastern Forest Experiment Station selected a 10% subset of their survey plots located in natural stands of loblolly pine in the 23-county region studied in central Georgia (fig. 1). FIA plots are random samples of forest land located on the landscape in a systematic fashion using photo grid points. Since the 1950's decade, trees have been measured at each of these samples at 10-year intervals and were re-inventoried in 1985.

Criteria for selection of the subsample required that plots were located in relatively undisturbed natural evenaged stands of the loblolly pine type between the ages of 25 and 50 years in 1984, with stand density within the normal range of basal areas and stocking levels, on typical upland pine sites of site index between 20 m and 28 m (at age 50 years). All stands selected for study were free of major disturbances over the survey period, and in 1985 there was no evidence of fire, severe insect or disease infestations, thinnings or other harvest. Most stands included normal numbers of trees with fusiform infections, bark beetle mortality, ice and glaze breakage, and other typical on-going impacts. Hardwoods were

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[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2/] Respectively, Professor, Department of Forestry, Clemson University, Clemson, SC 29634, and Project Leader, Southeastern Forest Experiment Station, Athens, GA 30602.

[3/] This research was supported by the National Vegetation Survey, National Acid Precipitation Assessment Program, through the Southeastern Forest Experiment Station USDA Forest Service, Asheville, N.C.

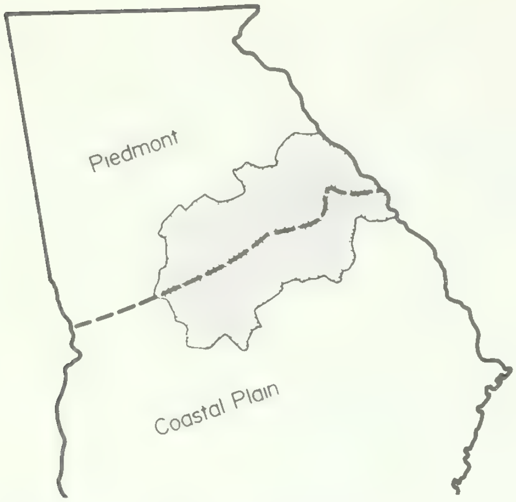

Figure 1.--Location of the 23-county study area in central Georgia.

present as understory and midstory in all stands, and as a component of overstory in some stands. A total of 38 plots were selected for the dendroecological analysis.

Increment Cores

Two increment cores were extracted at breast height from opposite sides of the bole on each of a minimum of five trees on each plot. Sample trees were selected subjectively as representative of healthy, undamaged dominant and codominant crown classes. The cores were prepared for measurement, cross-dated by visual inspection, and rings measured to an accuracy of .01 mm with a digital micrometer using standard techniques (Phipps 1985). Cross-dating for these short chronologies was aided by the occurrence of clearly defined signal years throughout all ring sequences. Thus, all tree-ring measurements were absolutely dated.

Average ring width for each year of the respective tree-ring sequences for each plot was calculated from the ring-width measurements of individual cores. Average ring widths were plotted over calendar years for each plot (fig. 2). Juvenile wood was eliminated by using ring measurements at age 15 years and older. As clearly indicated by the trend line in figure 2, ring-width sequences in these short-term, relatively young tree chronologies exhibit strong exponential decay curves with increasing age, following the initial period of juvenile wood formation.

The Age Factor

The greatest single effect on ring widths in young evenaged stands is that of tree age (Fritts and Swetnam 1988, Zahner 1988), further discussed in the tree-ring model below. To analyze the impacts of environmental factors, tree rings must be compared from stands of equal age. Therefore, the first step in the analysis is to remove the effect of age. Beginnirg with total stand age in 1984 (as determined from average ring counts at breast height plus three years), a time series for stand age was established for each plot. The oldest stand in the 38-plot sample was 47 years in 1984, and the youngest was 27 years. The limited sample size for older stands excluded analysis for years prior to 1960. Several plots in the original survey had been dropped because increment cores indicated the stands were not truly evenaged.

An age was assigned to each ring-width measurement for each calendar year back to age 15 for each stand. The final sample was represented by all 38 plots for 20-year-old stands from 1957 through 1978, by all 38 plots for 25-year-old stands from 1962 through 1982, and by only 29 plots for 30-year-old stands from 1967 through 1984. It was decided to limit the tree-ring analysis to 25-year-old stands because this age class contained all 38 plots for the most recent and longest period of time.

An average ring width for the 25-year age class was established by calendar year for each plot (fig. 2). This age class includes measurements of tree rings two years previous and two years subsequent to the calendar year when a stand was 25 years old. The ring width assigned to a plot at age 25 is, therefore, the average ring width of a 5-year moving average. Calendar years for this age class are well distributed across the period from 1960 through 1984 for the 38 plots (fig. 3).

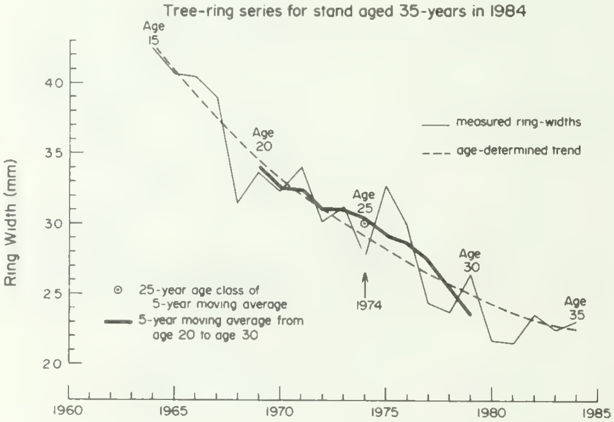

Figure 2.--Example of tree-ring time series for one plot. This stand was 25 years old in 1974, and the ring width for this age class is calculated as the average of 5-year moving averges from 1972 through 1976. The long term trend (dashed line) represents the ring-width decay curve due to increasing age.

Tree-Ring Model

The analysis used in this study is an adaptation of Graybill's (1982), Cook's et al. (1987) and Zahner's (1988) linear aggregate models for the potential components of tree-ring variation, the latter of which suggests in particular a method for examining growth declines. The dependent variable RW_t, representing a ring-width measurement accurately dated to calendar year t, is modeled as the aggregate of seven basic components of the equation

$$RW_t = f(AGE_t, C_t, ENDO_t, EXOG_t, S_t, YR_t, e_t)$$

where:

AGE = The age-related growth trend in year t that is shared by all dominant and codominant loblolly pine trees in a given stand on a given site. This trend is the ring-width decay curve associated with increasing stand age that arises from the geometrical constraint of adding tree rings to stems of increasing diameter. In the current study, age is eliminated as an independent variable because the analysis is limited to 25-year-old stands.

C = The climatically-related growth variations common to the given stand of trees in year t, including current weather, lagged preconditioning climate, and the interaction of climate with site. The rainfall and temperature patterns of each growing season were modeled with the DISP simulation, as described below.

ENDO = The endogenous growth pulse within the given stand, originating from changes in competition, stand structure and stocking levels acting on sampled trees in year t. This component is measured by a stand density index, described below.

EXOG = The exogenous disturbance pulses in year t originating from forces outside the given stand, such as those resulting from harvesting, ice storms, insects or disease. This component does not enter the current analysis because all stands exhibiting abnormal disturbance were eliminated from the original FIA field selection of plots or later by the examination of increment cores.

S = Independent site-related growth variation, reflecting the edaphic characteristics of soil, topography, and geology that regulate productivity for the given stand, a constant for all t years. (1) A dummy variable indicating Piedmont or Coastal Plain location and (2) measured site index were used as two independent variables for each plot.

YR = The abbreviation for calendar year, a measure of the independent effect on ring width of the passage of time, in year t, unrelated to the age of the stand. For a population of stands, a change in ring widths related independently to this component within a given age class represents an increase or decrease in radial growth over time (Zahner 1988).

E = Error, the random variance in ring width in year t due to unmeasured growth-influencing factors as micro-sites, genetic composition, variation in radii around the circumference of boles, and mis-measured site, climate, tree or stand variables.

With the age component fixed as a constant, the above model describes three additional components that are known to contribute to radial growth variance in undisturbed even-aged stands of loblolly pines: Climate, stand density, and site. A suspected growth change associated with the passage of time, the YR component, can be identified only after analysis has quantified the effects of the known components (Zahner 1988). Multiple regression analysis was used to test the significance of each component in the linear aggregate model as an appropriate technique to fit the measured field and laboratory data to a time trend (Draper and Smith 1966). The analysis was applied to the tree-ring measurements shown in figure 3.

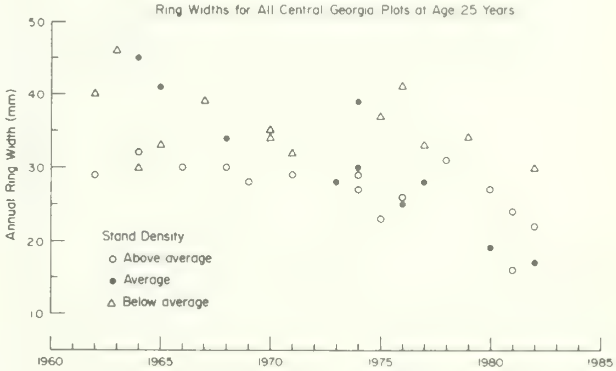

Figure 3.--Age class 25 ring widths of all 38 stands plotted over the calendar years in which respective stands were 25 years old. Also indicated are three levels of stand density, with the average level between 4.5 and 6.5 SDI units.

Climate

A simulation model was developed to assess the impact of climate on the tree-ring sequences. The model calculates a new index, DISP (Drought Index for Southern Pines), that permits adjustments to annual growth increments due to favorable or unfavorable climate, just as site quality adjustments to growth are estimated with site index (Zahner and Grier 1989). DISP makes use of both the timing and intensity of wet and dry weather during a current growing season plus two years of preconditioning antecedent weather to calculate departures from the long-term average, or normal, pattern of radial growth.

DISP uses monthly values of the Palmer Drought Severity Index (Palmer 1965) as the sole climate input variable because this index is an integrated measure of the daily and monthly maximum and minimum temperatures, precipitation, and soil moisture regimes impinging on forest vegetation at a given season of the year at a given geographic location. The Palmer Index is the National Weather Service standard indicator of relatively wet and dry local conditions, and monthly values of the Palmer Index are readily available for all geographic locations throughout the United States (Karl and Knight 1985, NOAA 1988).

The concept and application of the DISP model to assess the impact of climate on the growth of the southern pines have been reported elsewhere (Zahner and Grier 1989). The model is intended for stand level growth responses in adequately stocked, evenaged pine stands. It is not concerned with growth rates per se, but with growth at any given time relative to the long-term average growth in any stand relative to itself.

DISP values were calculated from monthly values of the Palmer Index for each year for the period 1960 through 1954 for the Central Georgia Climatological Division of the National Weather Service (table 1). Figure 4 shows these annual values plotted with the five-year moving averages of DISP for this 25-year period.

Stand Density

Basal areas and numbers of stems per hectare, of both pine and hardwoods 2.5 cm dbh and larger, had been measured on all plots at four points in time, at the ten-year FIA survey intervals in 1961, 1972, and 1982, and in the 1985 inventory. Curve fitting of basal area and number of stems over time for these survey dates, separately for each plot, permitted the interpolation of stand density within survey cycles for each calendar year for which there were tree-ring measurements for that plot.

A stand density index (SDI), a function of basal area times number of stems, was assigned to each plot for that calendar year in which the stand was 25 years old. Twelve stand density classes resulted from the numerical range of combinations of basal area and number of stems: from minimally stocked class 1 with basal area less than 14 m^2/ha x 700 stems/ha, to maximally stocked class 12 with basal area 40 m^2/ha x 2,000 stems/ha. This stand density index (SDI) was based on the rationale that competition for pine growth from understory and midstory hardwoods is related to increasing numbers of all trees larger than 2.5 cm dbh.

SDI values at age 25 years for the 38 plots are not randomly distributed through the 25-year period. The average SDI in 1984 is significantly larger than in 1960 (fig. 5). The plotted points indicate there is much greater variation in SDI values within calendar years than between years (figs. 3 and 4). Nevertheless, 25-year-old stands of natural loblolly pine have higher stand densities in the 1980's then in the 1960's. This finding is consistent with those of Lloyd and Waldrop (1988) and Zahner et al. (1989).

Sites

The 38 plots are located along both sides of the Fall Line that separates the Piedmont from the Coastal Plain in central Georgia (fig. 1). From detailed soil surveys of the counties along the Fall Line, from field inspection, and from the forest habitat map of Georgia (Pehl and Brim 1985), it was determined that 18 plots occurred on Coastal Plain soils and 20 plots in Piedmont soils. No plots occurred on Sand Hills soils, and all plots in both Piedmont and Coastal Plain provinces were on Ultisols and Alfisols with clay to sandy clay loam subsoils.

Sites supporting natural stands of loblolly pine in central Georgia are drought-prone because of the hilly terrain, past land abuse, and potentially restrictive rooting depth (Zahner and Myers 1986). Pine stands have seeded naturally onto sites that have been periodically disturbed by European man for over 200 years. Almost all of the 38 stands were located on sites that indicated prior agricultural land use, exhibiting from mild to severe erosion of the original surface soil.

Site index at age 50 was measured on each plot using standard site equations for loblolly pine (Farrar 1973). Site index is randomly distributed among plots for those calendar years in which each stand was 25 years old. In other words, these natural stands of loblolly pine when aged 25 years were growing on similar sites in the 1960's as in the 1980's.

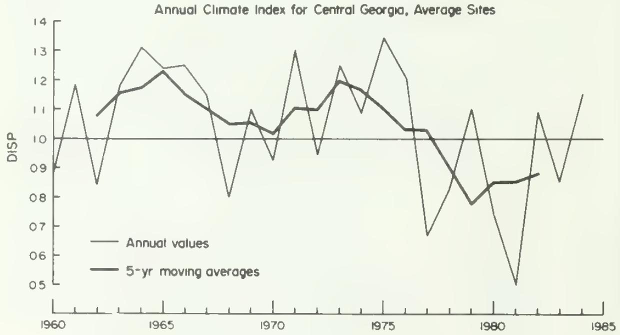

Figure 4.--DISP values plotted over calendar years for the period 1960-1984. Values greater than 1.0 are relatively wet years and values less than 1.0 are relatively dry years. The 5-year moving averages of DISP values between 1962 and 1982 were used in the tree-ring analysis.

Table 1.--Annual DISP values calculated for the central Georgia climatic division for the period 1960-1984

Year	DISP Value	Climate - Growth Impact Rating
1960	0.885	Growth moderately less than average
1961	1.195	Growth moderately greater than average
1962	0.841	Growth moderately less than average
1963	1.179	Growth moderately greater than average
1964	1.319	Growth potential maximum
1965	1.244	Growth substantially greater than average
1966	1.247	Growth substantially greater than average
1967	1.142	Growth moderately greater than average
1968	0.799	Growth moderately less than average
1969	1.107	Growth moderately greater than average
1970	0.930	Average growth (+ or - 10%)
1971	1.306	Growth potential maximum
1972	0.940	Average growth (+ or - 10%)
1973	1.249	Growth substantially greater than average
1974	1.094	Average growth (+ or - 10%)
1975	1.340	Growth potential maximum
1976	1.202	Growth substantially greater than average
1977	0.677	Growth substantially less than average
1978	0.834	Growth moderately less than average
1979	1.110	Growth moderately greater than average
1980	0.748	Growth substantially less than average
1981	0.508	Growth severely limited
1982	1.093	Average growth (+ or - 10%)
1983	0.863	Growth moderately less than average
1984	1.164	Growth moderately greater than average
25-yr ave	1.041	Average growth (+ or - 10%)

Passage of Time

Time is measured in this study by calendar year. It is assumed that potential impacts of regional atmospheric deposition on radial growth of Piedmont loblolly pine likely occur as exogenous factors accumulating over time (Zahner et al. 1989). Tree-ring "declines" that cannot be associated with natural factors over all stands in a region, and that are correlated with the passage of time, could be associated with atmospheric deposition.

RESULTS

The multiple regression analysis resulted in the following relationship, in which all independent variables are highly significant (table 2), with an $R^2 = .69$:

$$(1)\quad RW = 4.086 - 0.127\ (SDI) + 0.084\ (SI) + 1.014\ (DISP) - 0.0469\ (YR).$$

This solution is not step-wise. Variables are purposely entered in the order given, first to explain sequentially the variation due to factors that are known to affect radial growth. The YR variable is entered last, representing unexplained growth factors associated with time. It is this final variable that has the largest effect on ring-width variation.

With other factors held constant at their long-term means, the regression equation calculates the independent effect of the passage of time (YR) on tree-ring development. Simulations for 25-year-old stands of mean stand density per site class constant over time, and for a constant climate, with an average ring width of 3.8 mm in 1960, show an unexplained reduction in ring widths over the 25-year period to 2.7 mm in 1984, or about one percent per year (fig. 6).

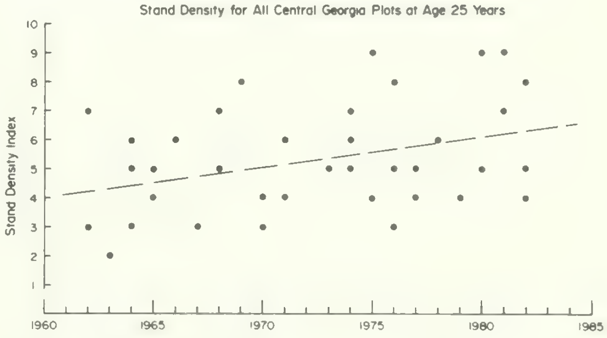

Figure 5.--SDI values for the 38 stands plotted over the calendar years in which the respective stands were 25 years old. There is a significant (2% level) regression slope of 0.1 SDI unit per year from 1960 to 1984.

Table 2.--Statistics for regression equation (1). Variables listed in order of entering analysis (prescribed order, not stepwise). Constant = 4.086

Variable	Mean	Coefficient	Standard Error	Prob. b = 0	Sequential R^2
SDI	5.4	-0.1268	0.0403	0.003	.416
SI	24 m	0.0840	0.0270	0.004	.458
DISP	1.06	1.0141	0.7179	0.047	.568
YR	72.6	-0.0469	0.0127	0.001	.693

The effect on tree rings of stand density is indicated by the coefficient for SDI in the regression equation. Within any calendar year ring widths vary more than 50 percent as stand density indices vary widely from stand to stand (fig. 3). Additionally, over the 25-year period, the effect of increasing average stand densities from a SDI of 4 in 1960 to 6 in 1984 results in average ring-width decreases of about 8 percent due to this endogenous variable alone (fig. 6).

The interactive variables SDI x Age, SDI x YR, and SDI x Age x YR did not significantly improve the regression R^2 for the tree-ring model. Therefore, the calculated declines in ring widths due to changes in stand density over time are constant through time, and given stand densities early in the 25-year period have the same effect on tree rings as later in the period. Although the SDI x YR interaction is highly significant when used alone in lieu of SDI and YR separately, SDI x YR did not improve R^2 over the two individual effects in the linear model. Additionally, principal components analysis and ridge regression analysis (Draper and Smith 1966) failed to allocate further the individual effects on ring widths of increasing SDI over time and the passage of time alone.

The effect of site quality, SI in the regression equation, is significant. As pine sites change from lowest to highest, average ring widths increase about 22% for average stand densities. This is in agreement with the Brender and Clutter (1970) yield tables that show yields of 25-year-old natural loblolly pine stands in the Georgia Piedmont increasing about 8% per 3-meter site class under average stocking conditions. There was no significant difference in ring widths due to Coastal Plain versus Piedmont locations.

Significant changes in climate are discernible over the 25-year period. Five-year moving averages of the DISP regional climate simulation show clearly that the period 1960-1984 encompasses two distinct climatic intervals for central Georgia (fig. 4). The 17 years from 1960 through 1976 were generally favorable for radial growth of the southern pines. This interval includes no extreme droughts and contains two periods in mid-1960's and mid-1970's comprised of generally favorable growing conditions with most years substantially wetter than normal. Beginning with a moderate drought in 1977, the 8-year period through 1984 was generally unfavorable for radial growth. Although 5 years during this interval were near normal, the three years of moderate and severe drought generally reduced tree-ring widths.

In the regression analyses, the 5-year moving average of DISP has a significant influence on ring width. This variable increases ring width by about 10 percent in years when there has been a favorable growth period, and decreases ring width by the same proportion when there has been an unfavorable period. The accumulated effect of regional climate, therefore, changing first from generally favorable and then to droughty over the 25-year period, modifies the ring-width decline slope to a curvilinear trend from 1960 through 1984 (fig. 6).

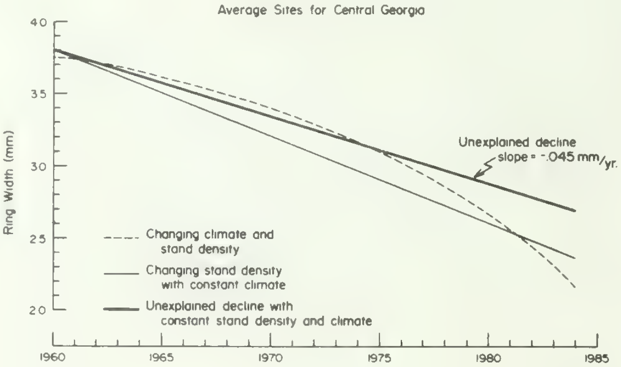

Figure 6.--Graphic solution of regression equation (1), with SI held at mean value and other variables constant or changing with calendar year as indicated. The regression slope of -.045 mm/yr is equal to about a 1% decline in ring width per year over the 25-year period.

DISCUSSION AND CONCLUSION

This dendroecological analysis of loblolly pine tree rings from natural undisturbed stands throughout central Georgia shows that a total decline in radial growth of 40 percent occurred over the 25-year period 1960-1984. This decline is not associated with changes in site productivity or changes in stand ages. Upland sites in this region are susceptible to drought as an on-going predisposing stress factor (Zahner and Myers 1986). The dry years of 1980-81 contributed to the decline and no doubt accelerated it. Favorable climate had ameliorated the decline during the middle of the period, whereas drought increased the decline sharply later in the period. A seven percent decrease in ring widths is attributable to the change in climate. Without the cyclic impacts of favorable and droughty climate, the ring-width decline is apparently linear with time (fig. 6).

The decline is partially associated with changes in stand density, as both basal area and number of stems per hectare have increased significantly in these natural pine stands over the 25-year period. Average ring widths in 1984, therefore, were somewhat narrower than in the early 1960's, independent of site quality and climate, due to the higher average basal areas and stocking levels supported by natural stands that were established and matured later in the period. The tree-ring analysis indicates that this change in average stand density with time results in an eight percent decrease in ring widths over the 25-year period.

The combined effects of changing climate and stand density, therefore, account for less than half of the total decline in ring widths over the 1960-1984 period. The major decline in ring widths, about one percent per year, is associated with the passage of time, independent of the measured environmental and endogenous stand factors. From this analysis, it is concluded that trees in natural evenaged stands of loblolly pine at the age of 25 years in central Georgia were growing in the early 1980's at about three-quarters the annual radial increment that equivalent trees in stands of the same age on the same sites were growing 2 1/2 decades before.

The results of this study have been verified recently by Zahner et al. (1989) who report a 1% per year reduction in radial growth for natural stands of loblolly pine throughout the Piedmont region of Georgia, South Carolina, and North Carolina. After adjusting for effects of age, site, climate and stand densities, their analysis found annual radial growth was down 36% from 1949 to 1984. The regional climate change between these two periods was responsible for a portion of this reported growth decline; but as in the present study, other significant causal factors remain unidentified.

Lloyd and Waldrop (1988) also report unexplained recent reductions in growth in natural stands of loblolly pine. After adjusting for age, basal areas, and site, they found a 17 percent lower annual basal area growth for the 5-year period 1976-1980 than for an earlier 1955-1959 period in the Coastal Plain of Virginia, and a similar reduction in annual basal area growth between the period 1977-1981 and the earlier 1955-1959 period in the Coastal Plain of South Carolina.

In addition to climate as an exogenous time-related factor operating over central Georgia, the one man-caused exogenous factor potentially affecting all pine stands in this region is atmospheric deposition. Shafer et al. (1987) report reductions in growth of juvenile loblolly pine under ambient levels of ozone stress in controlled field experiments in the Piedmont of North Carolina. It is well documented that ozone concentrations are high throughout forested areas of the Piedmont region (Pinkerton and Lefohn 1987) and in particular in central Georgia (Rodgers and Chameides 1988). Any impact of this pollutant on forest health is likely to be time-related.

In summary, the 25-year declines in ring width are time-correlated with changes in stand density, climate and with unidentified other stress factors. As central Georgia pine stands passed through the favorable climate during the middle of the period, radial growth may have failed to respond positively perhaps because of unidentified predisposing stresses combined with increases in stand density. As these pine stands later passed from the favorable climate era into the unfavorable later period, radial growth may have declined rapidly in response to the combined stresses of droughty climate, increases in stand density, and possibly regional ozone pollution. A significant portion of the simulated decline cannot be dismissed as climatic and competition effects. The regional trends in ozone and other possible pollutants should be seriously considered as correlative agents.

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SIMULATING THE EFFECT OF ATMOSPHERIC DEPOSITION ON LOBLOLLY PINE STANDS[1]

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Charles D. Webb[2]

Abstract.--A prototype of a new loblolly pine (Pinus taeda L.) growth model has been developed that contains an area and a height-based competition index. The new model is flexible and allows forest scientists to simulate some of the possible effects of atmospheric deposition on the growth and development of loblolly pine stands.

Simulation results revealed that compensation in standing volume per acre may occur in two distinct ways, depending on the nature of the susceptibility of individual trees to air pollution. Compensation can arise both from fewer surviving trees per acre of larger mean size and from more surviving trees of smaller size. When irregular spatial patterns arose in simulated stands as a result of hypothesized air pollution mediated disturbances, compensation was inhibited.

INTRODUCTION

In the United States there is a growing concern that air pollution is affecting the health of both natural and artificially regenerated forests. Unfortunately, definitive studies designed to detect and quantify air pollution effects on forest stands are, at best, complex, expensive, and long-term. Until these studies are executed and the data analyzed and interpreted, forest scientists will be severely hampered in their efforts to address the problem.

An interim and complementary approach to the problem involves the use of forest stand growth and yield simulators to model the hypothetical effects of air pollution on forest stands (Webb and Burkhart 1988). This approach offers forest scientists a framework within which some of the many possible effects of air pollution on forest stands can be studied and contemplated.

As more long-term experiments are installed and monitored, the performance of forest stand simulators should be improved by comparing simulated responses to actual data. This experimental feedback can be used to modify the simulators so that they provide more realistic projections of forest stand growth and development in the presence of various air pollution regimes. By constantly verifying, modifying, and improving forest stand simulators in this way, there is hope that these mathematical models can provide reasonable assessments of possible air pollution effects now and in the future.

The objectives of the study discussed in this paper were: (1) to describe some hypothetical effects of air pollution on the growth and development of forest stands, (2) to describe how a forest stand simulator might be used to model some of these hypothetical effects, (3) to briefly describe a prototype of a new loblolly pine forest stand simulator designed to carry out some of the desired simulations, and (4) to summarize and interpret the results of several air pollution simulation studies that were produced by the new prototype simulator.

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HYPOTHETICAL AIR POLLUTION EFFECTS

The health and productivity of forest stands is dependent on a large number of factors that interact in space and time (Spurr and Barnes 1973). Abiotic site factors (such as precipitation, light, carbon dioxide, temperature, and physical and chemical soil properties) are important in determining the potential of the forest site for supporting tree growth. Biotic factors (such as soil organisms, diseases, insects, and the number, spatial pattern, and genetic potential of the trees occupying the site) interact with one another and with the various site factors to determine the actual or realized growth of trees on a given forest site.

In considering the possible effects of ambient air pollution on the health and productivity of forest stands, an already complex system is made even more complex. Airborne pollutants such as ozone, sulfur dioxide, nitrous oxide, heavy metals, and various other toxic chemicals add to the list of abiotic factors that could affect site quality directly or by interaction with other site factors. Similarly, airborne pollutants could affect the physiological growth processes of trees and other organisms either directly, as in foliar damage, or indirectly, through various interactions with other abiotic and biotic factors.

To complicate matters further, it is very likely that the effects of air pollution vary from tree to tree within a given forest stand (Houston and Stairs 1973, Scholz and Bergmann 1984, Mejnartowicz 1984). This is likely because: (1) trees within a forest stand are usually genetically different from one another, and this genetic variation could result in differential response to air pollution factors; and (2) forest sites are relatively heterogeneous with respect to soil, microclimate, and size and spatial distribution of trees and other organisms, which could affect the distribution and intensity of air pollution effects within a stand.

THE SIMULATION APPROACH

In the simulation approach, one is forced to abandon generalities and qualitative statements and instead provide exact quantitative descriptions of hypothetical air pollution effects. The simulation approach thus serves to focus and clarify ideas on the subject. For example, before attempting even a basic simulation of hypothetical air pollution effects on a given stand, one might attempt to formulate quantitative answers to the following set of questions:

1. Which trees within the stand are being affected?
    A. What proportion of the trees are being affected?
    B. What is the spatial distribution of the affected trees within the stand?
    C. What is the size distribution of the affected trees within the stand?
2. Is the growth of the affected trees reduced?
    A. Are growth reductions the same for all affected trees?
    B. Are growth reductions proportional to the tree's size?
    C. Are growth reductions related to the tree's spatial position?
3. Are affected trees killed outright?
    A. Do mortality events occur in a single episode?
    B. Do mortality events recur at regular intervals?

Given specific quantitative answers to these and related questions, one could then modify a suitable forest stand simulator to accept the required modifications. The simulator must not only be flexible enough to allow such modifications, but it must also provide realistic feedback on the possible effects of these modifications on forest stand growth and yield.

Stand simulators are needed that provide the flexibility and predictive power required for simulations of air pollution effects. Among the currently available stand simulators, the type that appears to offer the most promise for accomplishing the simulation of air pollution effects are the distance-dependent, individual-tree simulators. Even these models are, at best, only capable of addressing the most basic hypotheses on possible air pollution effects.

A NEW FOREST STAND SIMULATOR

We chose to develop a new stand simulator for loblolly pine to accomplish simulation studies of hypothetical air pollution effects. The new model is based on extensive modifications to the PTAEDA2 (Burkhart and others 1987) simulator, but retains much of the original capabilities and features of that model and its predecessor, PTAEDA (Daniels and Burkhart 1975).

The most fundamental change made to PTAEDA2 was the replacement of its single competition index (a modified Hegyi index) with two new competition indices. The first is based on weighted and constrained APA (area potentially available) polygons (Nance and others 1988). The second is an unpublished modification of Ford and Diggle's (1981) height-based competition index (which we will hereafter refer to as THETA).

The modified THETA index is essentially the average of all angles formed by lines connecting the top of a subject tree with the top of each neighboring tree. Large negative angles are associated with a tree that is, on the average, much taller than its neighbors, and is therefore a dominant tree. Large positive angles are associated with a tree that is much shorter than its neighbors, and which is therefore a suppressed tree.

In addition to replacing PTAEDA2's competition index with the two new competition indices (APA and THETA), we reformulated and refit all the growth and mortality components in the model. This was done to better accommodate the new indices, to make the model more flexible, and to incorporate more biologically based constraints directly into the growth and mortality components. Hence, the new model (which is still in a prototype stage and which will be referred to hereafter as PTAEDA2/APA) is similar in basic structure to PTAEDA2, but the fundamental components of the model are much different.

SIMULATION PROCEDURES

During the simulation of growth in a loblolly pine stand, PTAEDA2/APA maintains a list of all the individual trees within the stand. The model stores each tree's height, diameter at breast height, volume, cartesian coordinates, APA, and THETA, as well as numerous other details specific to the individual tree.

To facilitate the simulations for this study, we elected to construct three general purpose subroutines designed to operate on PTAEDA2/APA's individual tree list. These were: (1) APSELECT, which identifies those trees in the list that will be affected by simulated air pollution effects; (2) APGROW, which allows for modifications in the growth of those individual trees identified by APSELECT; and (3) APMORT, which deletes trees selected by APSELECT.

Subroutine APSELECT accepts two inputs from the user: (1) P, the proportion of the trees in the stand that will be affected by air pollution effects; and (2) PSELECT, which specifies which one of two types of selection (random or exposed) will be used to identify the affected trees.

For PSELECT = RANDOM, a specified P proportion of the trees are randomly targeted for air pollution effects. This option mimics the hypothetical case where a proportion of the trees in a stand are genetically susceptible to air pollution effects, but the susceptibility is not related to any measurable attribute of the tree such as tree size or spatial position (Scholz and Bergman 1984). Random selection is accomplished by using a pseudorandom number generator that is independent of any of the tree's attributes. Under this option, once a tree is targeted for air pollution effects, its growth or mortality beginning at age 8 is impacted as specified by either APGROW or APMORT.

For PSELECT = EXPOSED, the P proportion specified will result in the most dominant trees being targeted for air pollution effects. The exposed option utilizes our height-based competition index (THETA) to identify trees with more exposed crowns. It also mimics the hypothetical case where increasing amounts of exposed crown subjects the tree to increasing effects of air pollution (IFER 1984). Unlike the RANDOM option, the EXPOSED option reselects the most exposed P proportion of the trees at the beginning of each growth period, and therefore any tree within the stand can be affected at any point in time if its crown is sufficiently exposed.

Subroutine APGROW accepts three inputs from the user, which correspond to the desired values for the three parameters of the Weibull distribution (Johnson and Kotz 1970). By inputting these three parameters, the user controls the distribution of growth reductions that are assigned to the trees selected by APSELECT. For PSELECT = RANDOM or PSELECT = EXPOSED, a growth reduction for a selected tree is generated in APGROW by randomly sampling from the probability distribution function for the specified Weibull distribution. The projected volume growth of the tree is then reduced by the sampled proportion through a simultaneous reduction in height and diameter growth, which achieves the desired volume reduction while maintaining the same diameter/height ratio that the tree exhibited at the beginning of the growth period. This approach reduces any possible effects on tree form while achieving desired growth reductions in total volume.

Subroutine APMORT accepts one argument, FREQ, which controls the frequency of the direct mortality effects in the model. When FREQ = ONCE (one episode), then the P proportion of the trees in the stand selected by APSELECT at age 8 will be eliminated from the tree list to simulate a sudden, direct mortality event. When FREQ = RECUR (recurring episodes), then a fraction of the selected trees will be eliminated at each projection period, beginning at age 8, to simulate a series of equal mortality events that, when accumulated through the entire projection period, will eliminate the P proportion of the trees in the stand.

Together, APSELECT, APGROW, and APMORT provide a powerful system capable of simulating many hypothetical effects on stand growth and development, including not only those related to air pollution but also those due to genetic variation as well as those due to many insects and diseases.

THE SIMULATION STUDY

To simulate stand development for a range of sites and densities, the site index (SI) and planted trees per acre (TPA) inputs to PTAEDA2/APA were varied as follows: (1) SI = 40, 60, 80; and (2) TPA = 400, 800, 1200. The projection age was fixed at 29 years for each of the nine site and density combinations.

Four P proportion values (0.25, 0.50, 0.75, and 1.0) were input to APSELECT for RANDOM and EXPOSED selections, which resulted in a total of

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eight different selection scenarios. The Weibull parameter inputs to APGROW were chosen to produce approximately bell-shaped distributions with mean growth reductions of 0.25, 0.50, and 0.75. These 3 growth reductions combined with the 8 selection schemes and the 9 site and density combinations result in a total of 216 different growth reduction simulations. For mortality simulations, the 2 inputs of the FREQ input variable to APMORT (ONCE or RECUR), when combined with 6 selection schemes (no P = 1.0) and the 9 site and density combinations, resulted in 108 mortality simulations. Additionally, a control stand (P = 0) was simulated for each of the nine site and density combinations. Hence, there were 333 simulations performed for the study.

For each stand simulated, stand summaries were output at ages 8, 11, 14, 17, 20, 23, 26, and 29 years. Size-density trajectories were then generated for each stand by plotting the natural logarithm of mean volume per tree versus the natural logarithm of surviving trees per acre at each of these ages and connecting the points to form a series of connected line segments (Drew and Flewelling 1977). Such diagrams are useful because they graphically expose differences between stands in patterns of growth and mortality over time as well as differences in total standing volume at any age.

SIMULATION RESULTS AND DISCUSSION

Although there were subtle differences between the 9 site and density levels for both RANDOM and EXPOSED simulations, we present here only the results for the site index 60 and 800 trees per acre combination as representative of the typical results obtained for the other 8 site and density combinations.

RANDOM Simulations

Figure 1a summarizes the results obtained for growth and mortality effects with RANDOM selection of 25 percent of the trees as susceptible. The trajectories for growth reductions of 25, 50, and 75 percent at this selection level (25 percent) show increasing mortality and progressively lower volumes compared to those of the control stand. This translation of growth reduction to increased mortality is perhaps expected because most (75 percent) of the trees in the stand are growing normally and are gradually overtopping and crowding out the slower growing susceptible trees, which are in a minority at this selection level. The reduced standing volumes still detectable at age 29 appear to be the result of the slow growth of susceptible trees that survived to this age in spite of their reduced growth rates.

The trajectories for the two mortality simulations (FREQ = ONCE and FREQ = RECUR) for the RANDOM selection at the 25-percent level (fig. 1a) show that the simulated stand with the early, single mortality event (FREQ = ONCE) had far fewer surviving trees (and less volume) at early ages compared to the simulated stand with recurring, but lower, levels of mortality. However, by age 29, the difference between the two trajectories had largely disappeared, and they each had approximately the same volume--although there were still somewhat fewer surviving trees in the FREQ = ONCE stand by age 29.

The results for RANDOM selection of 50 percent of the stand are shown in figure 1b. These trajectories show basically the same patterns of response to growth and mortality effects as the 25-percent RANDOM simulations, but the volume losses by age 29 were more than twice those for the 25-percent RANDOM simulations. The higher proportion of susceptible trees resulted in less stand-level volume compensation in the simulated stands.

The results for the RANDOM selection at the 75-percent level are shown in figure 1c. The growth effects in this simulation do not translate as strongly into mortality as did the 25- and 50-percent RANDOM simulations. In fact, the 25-percent growth reduction actually resulted in less mortality than the control stand with no growth effects. This can be attributed to an overall reduction in competitive pressure in the simulated stands due to the high proportion of trees that were affected.

The two trajectories for mortality effects for RANDOM selection at the 75-percent level (fig. 1c) also show somewhat different patterns compared to the previous RANDOM simulations. Here the recurring mortality scenario produces slightly less total volume by age 29 as well as fewer surviving trees than the single mortality event. Also, the pattern of mortality in the single event simulation was unusual in that there was essentially no additional mortality in this stand until age 23 (15 years after the mortality event), after which the mortality began to increase at a substantial rate even though the stand was still far below the region of the size-density space where self-thinning is expected. Further inspection of the spatial pattern in this stand revealed that the 75-percent random thinning resulted in clumped pockets of surviving trees with large gaps separating the clumps. As the trees developed under this spatial pattern, they eventually became crowded within the pockets and started to self-thin, even though there were still substantial gaps remaining in the stand.

The final (age 29) standing volume results of the RANDOM growth simulations are summarized in the volume reduction response surface depicted in figure 2. The surface is somewhat flat in the region of low proportion of susceptible trees with low growth reductions, but rises steeply outside that region. Hence, the ability of the stand to compensate in total volume is quite strong in this region, but it rapidly diminishes as the proportion of trees susceptible to growth reductions and the

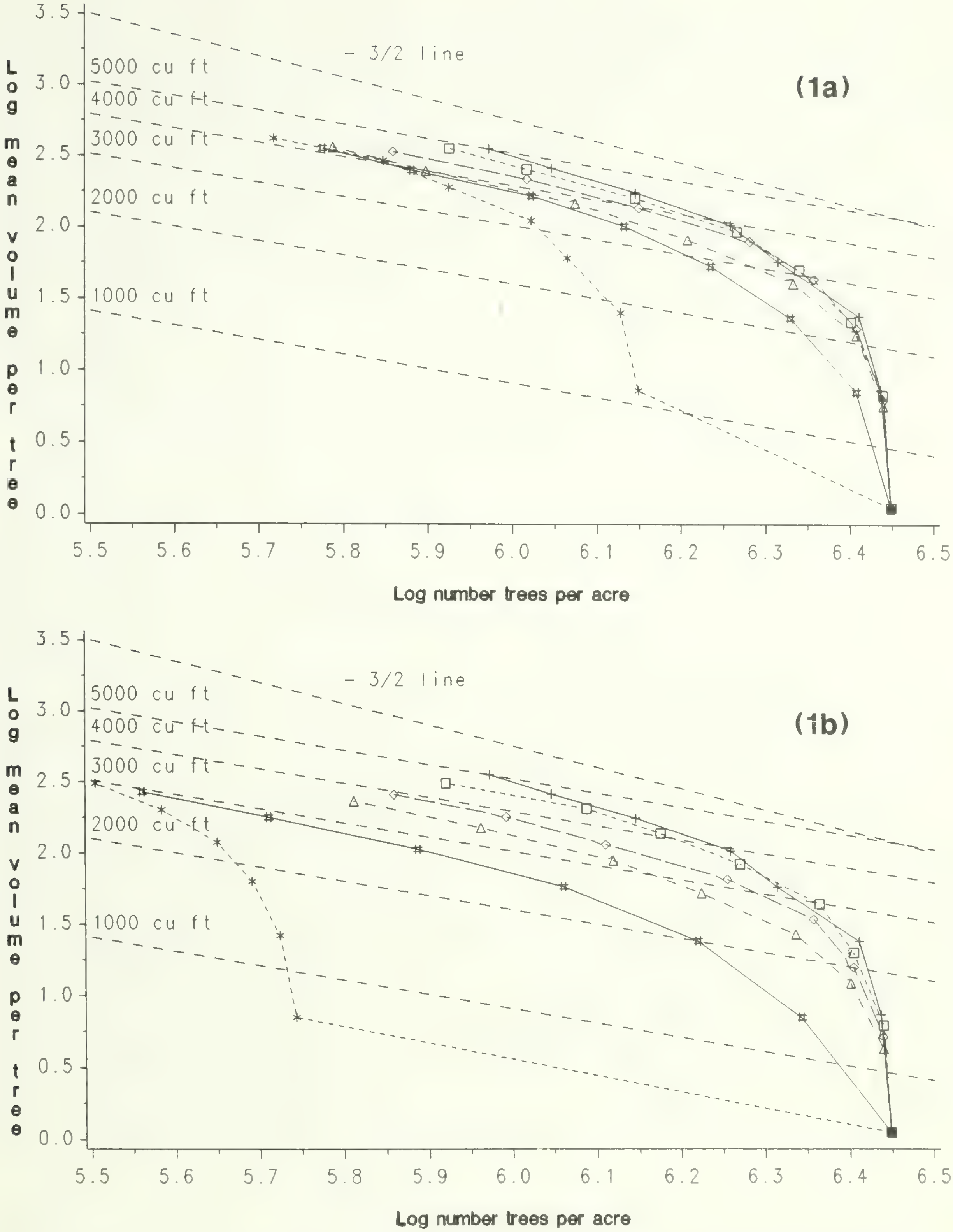


Figure 1.--Diagrams of the relationship between mean tree size and stand density when (a) 25, (b) 50 or (c) 75 percent of a simulated loblolly pine stand is randomly affected at 3-year intervals. Mean stem volume growth reductions include 0 (+), 25 (◻), 50 (◇), and 75 (△) percent. Direct mortality episodes include once at age 8 (*) and recurrent, ages 8 to 29 (#). The eight points on each line represent ages 8, 11, 14, 17, 20, 23, 26, and 29, going from right to left. Dashed lines represent total cubic foot volume per acre isolines and the -3/2 power line.

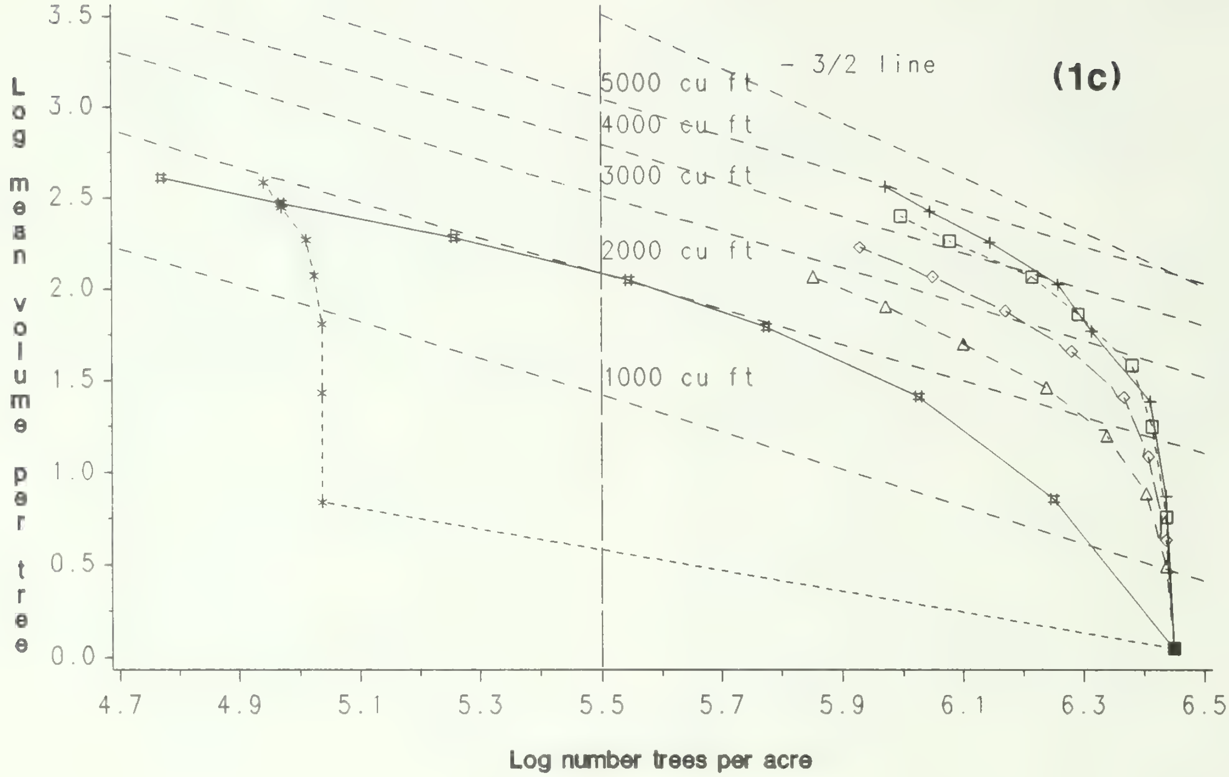


Figure 1.--Continued.

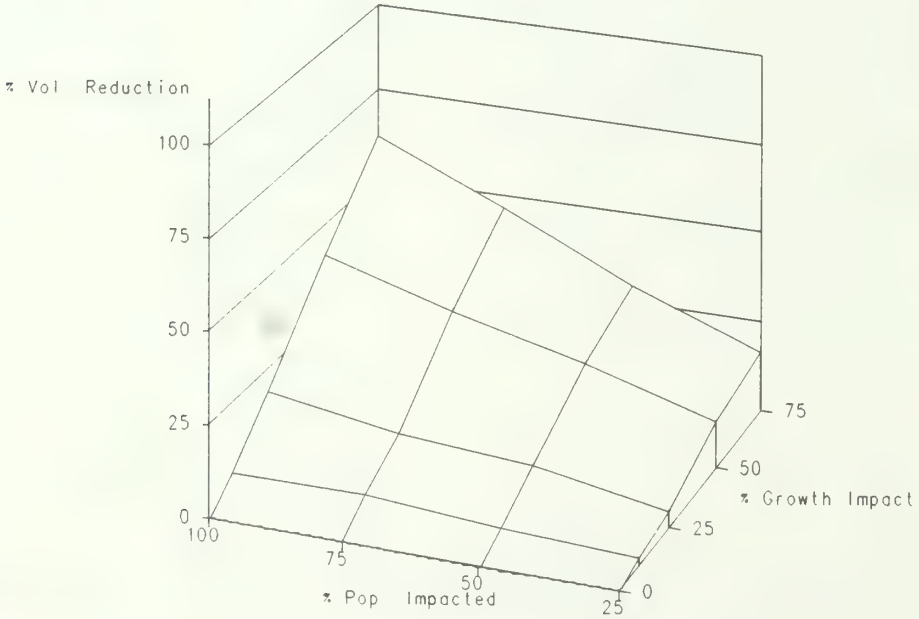


Figure 2.--Response surface of reduction in standing volume at age 29 of a simulated loblolly pine stand. The response is depicted as a function of the percentage of trees affected by random selection and the mean effect in volume growth reduction.

percentage of growth reductions are simultaneously increased.

The suggestion (offered by the RANDOM simulations) seems entirely plausible that the capacity of the stand to compensate for growth losses of susceptible trees would depend both on the proportion of susceptible trees in the stand and the severity of the growth reductions experienced by the susceptible trees. The suggestion that compensation might fall off rapidly when more than 50 percent of the trees exhibit growth losses in excess of 25 percent is also quite plausible, but perhaps not so obvious and more open to debate.

EXPOSED Simulations

The EXPOSED simulations for growth reductions at the 25-percent selection rate (fig. 3a) show much different patterns than the RANDOM simulations at the same selection rate. In the EXPOSED simulations, the affected stands show increased--not decreased--survival as the growth effects increase from 25 to 75 percent. However, the mean volumes per tree are also decreased, resulting in reduced volumes of approximately the same magnitude as produced by the RANDOM growth simulations at this same selection rate (fig. 1a). Hence, the trajectories for the P = 0.25 EXPOSED growth simulations appear to follow the same basic trajectory as the control stand, but their movement along this trajectory is increasingly slower as the growth reductions are increased. This pattern is similar to that observed when stands with the same initial planting density but different site indexes are simulated.

The EXPOSED mortality trajectories at the 25-percent selection level also show a different pattern compared to the RANDOM simulations at this level. In the EXPOSED simulations, the recurring mortality scenario results in fewer surviving trees at age 29 than the single event simulation. In spite of this, the total standing volumes at age 29 for the EXPOSED mortality trajectories are nearly equal, although less than the total volumes produced by the RANDOM mortality trajectories at this same selection rate.

The growth reduction simulations for EXPOSED selection at the 50-percent rate (fig. 3b) and the 75-percent rate (fig. 3c) show progressively slower movement along a common trajectory path, with some departure below the common trajectory for the highest growth reductions. The more severe growth effects under the EXPOSED growth simulations are decidedly worse in terms of total volume production than the worst RANDOM cases.

The mortality simulations for EXPOSED selection at the 50-percent (fig. 3b) and 75-percent (fig. 3c) levels also resulted in lower volumes than the RANDOM selections, although the two types of selection produce similar patterns of development. Since the most exposed trees also tend to be the largest trees in the stand, deleting these individuals severely deflates stand volume. Also, deleting exposed trees tends to create widening gaps in the FREQ = RECUR stands, since the trees bordering the gaps become more exposed to ambient air pollution.

The final (age 29) standing volume results of the EXPOSED growth simulations are summarized in the volume reduction response surface depicted in figure 4. The surface is somewhat flat in the rectangular region bounded by 50-percent selection and 25-percent growth reduction, but rises steeply outside that region. The relatively flat region for the EXPOSED response surface is smaller than the flat region for the RANDOM surface, which reflects the smaller degree of compensation detected in the EXPOSED simulations. Also, the slope outside this relatively flat region is somewhat steeper for the EXPOSED surface than for the RANDOM surface. This trend was also apparent in Webb and Burkhart's (1988) simulations of air pollution effects on loblolly pine stand growth and yield.

Conclusion

This simulation study is too limited in scope to reach any broad conclusions, but the results do appear to provide plausible feedback of how loblolly pine stands might respond to air pollution. There can be little doubt that factors such as genetic variation within stands and intertree competition play an important role in determining how stands respond to various influences such as air pollution. The research challenge is to recognize the importance of such factors and to properly incorporate them both into experiments and models.

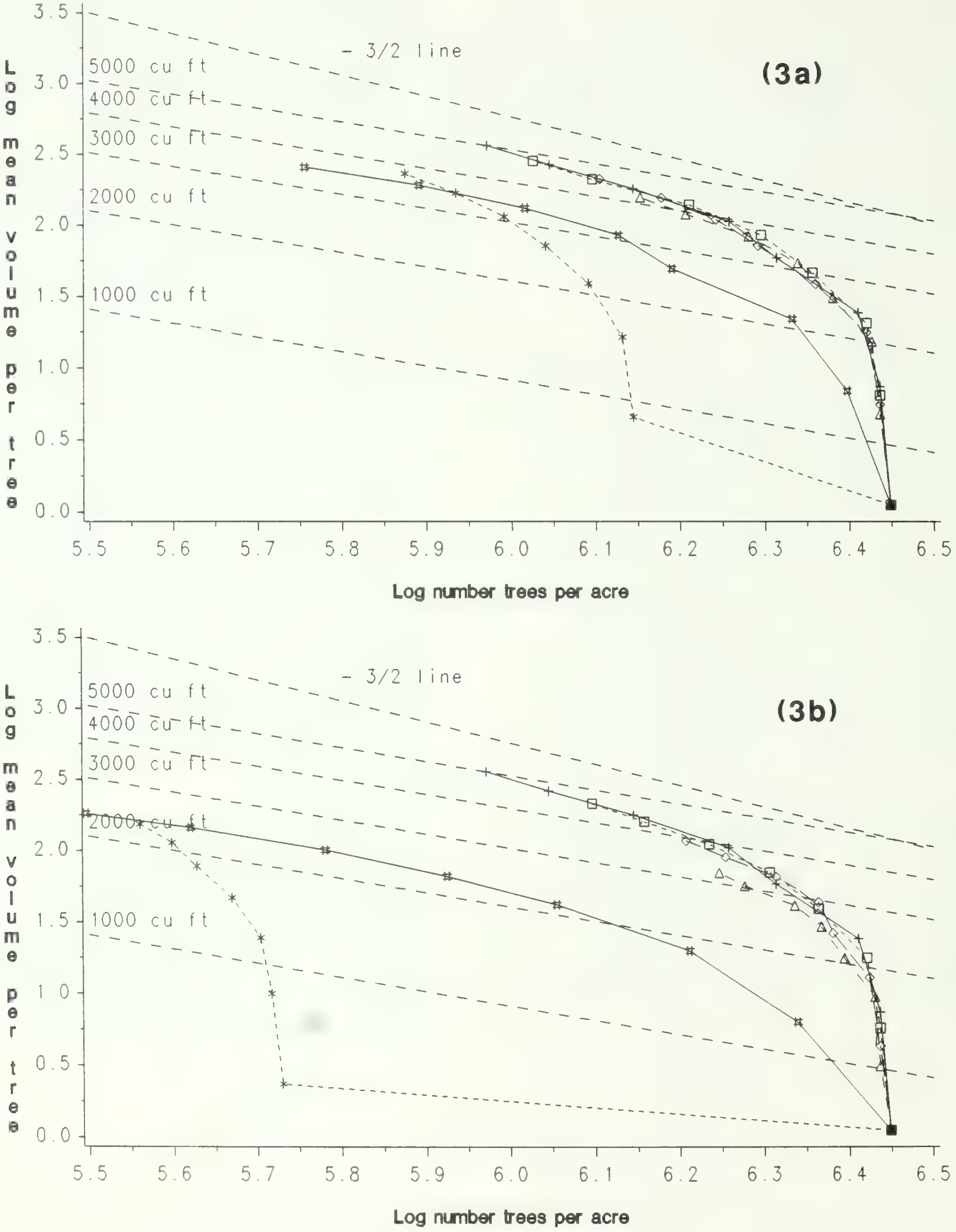
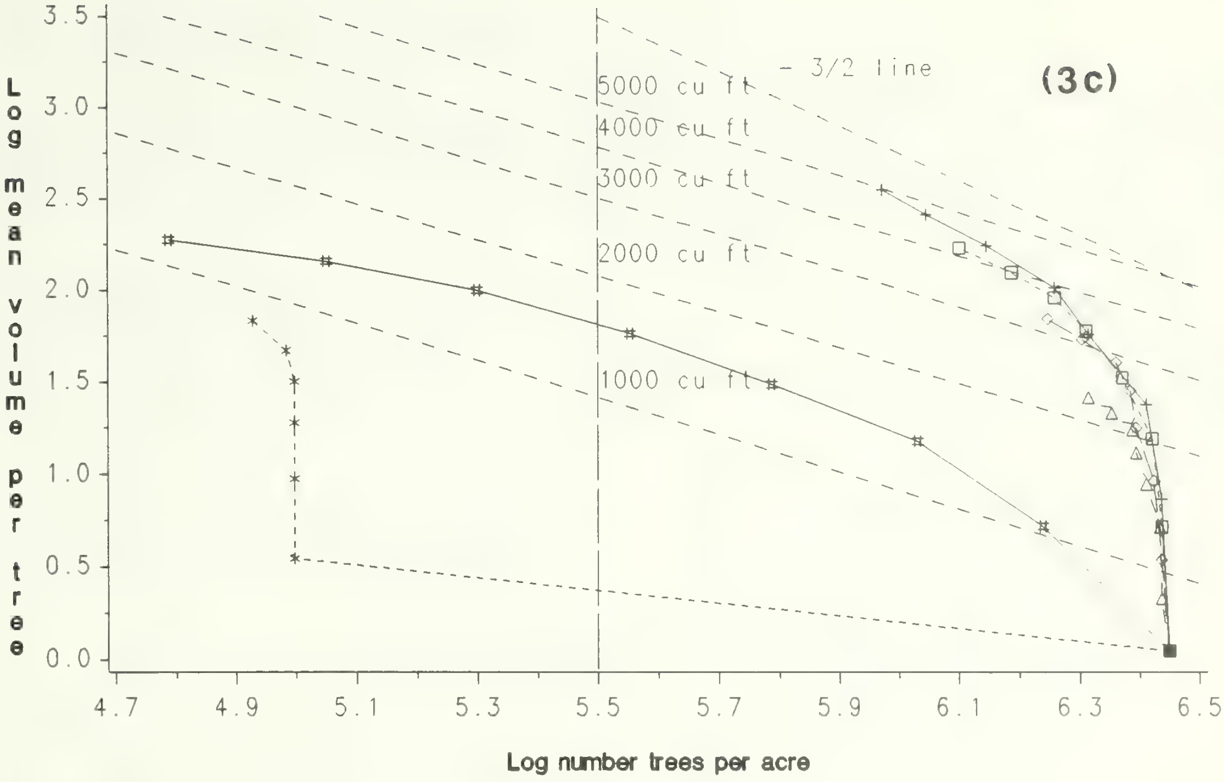


Figure 3.--Diagrams of the relationship between mean tree size and stand density diagram when (a) 25, (b) 50, or (c) 75 percent of a simulated loblolly pine stand is affected by level of crown exposure at 3-year intervals. Mean stem volume growth reductions include 0 (+), 25 (□), 50 (◇), and 75 (△) percent. Direct mortality episodes include once at age 8 (*) and recurrent, ages 8 to 29 (#). The points on each line and the dashed lines are as defined in figure 1.



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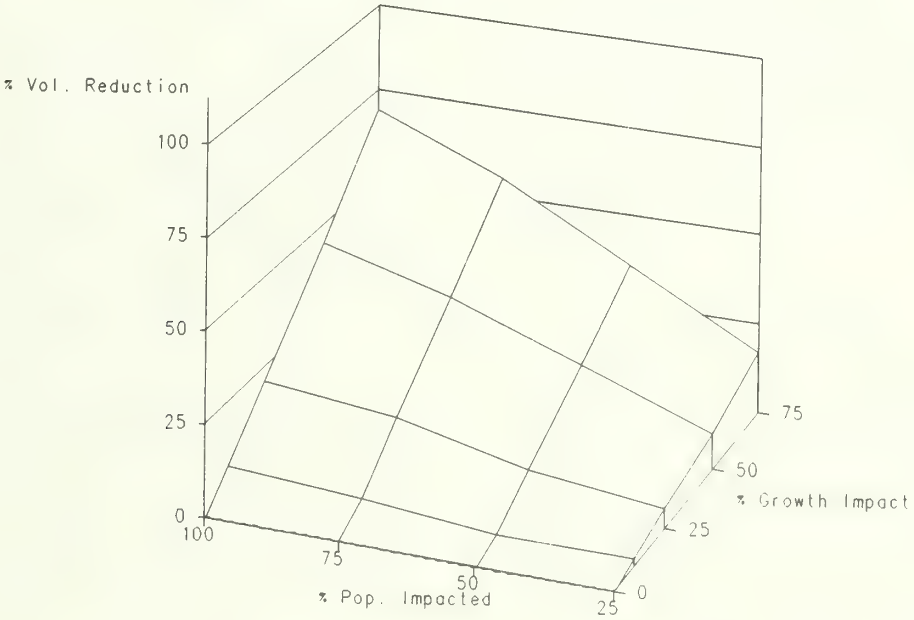

Figure 4.--Response surface of reduction in standing volume at age 29 of a simulated loblolly pine stand. The response is depicted as a function of the percentage of trees affected by the level of crown exposure and the mean effect in volume growth reduction.

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AN ANALYSIS OF SURVIVOR BASAL AREA GROWTH ACROSS THE RANGE OF LOBLOLLY PINE[1]

W. Rick Smith[2]

Abstract.--Annual survivor basal area growth of plots distributed throughout the natural range of loblolly pine (Pinus taeda L.) was analyzed using age, initial basal area of a growth period, and the proportion of basal area mortality as covariates. A tree ring analysis was used to select an appropriate weather variable as a covariate to account for climatic differences in location. The analysis of separate slopes resulted in significant interaction terms in three locations; however, the cause of the interaction terms could not be determined from the analysis.[3]

INTRODUCTION

Analysis by Sheffield and others (1985) of the continous forest inventory plots of the USDA Forest Service Southeast Region indicated reductions in loblolly pine (Pinus taeda L.) radial growth rates from the 1950's to the present. The Southwide Pine Seed Source loblolly pine provenance study (Wells and Wakeley 1966) was selected for analysis to investigate if growth declines could be detected for plots planted in 1952 that were distributed over the range of loblolly pine grown. The period analyzed was from 1963 to 1982.

The primary objectives in this study were: first, to detect differences in growth rates by location and second, to decide if atmospheric deposition was indicated as a cause in areas of detected growth decline. The detection of differences in growth rates by adjusting for stand dynamics and climatic factors was conducted through an analysis of covariance. The analysis of the affect of atmospheric deposition was not possible directly due to a lack of atmospheric deposition variables for the time period studied. Any conclusions made as to the influence of atmospheric deposition on growth had to be made in an indirect manner.

THE DATA

The Southwide Pine Seed Source study was established between 1952 and 1953. A total of 15 plantations established in 10 counties and 1 parish (fig. 1) were used in the analysis. Each plantation was a randomized complete block design with four blocks. A total of 15 seed sources was used, with 8 to 9 seed sources per block. Each plot in a block consisted of 49 measurement trees and 2 border rows planted in a 6- by 6-ft square spacing. The diameters at breast height were not measured until age 10 (1963) and were remeasured four times. The majority of the growth intervals were 5 years in length and ranged between 3 and 7 years. The last remeasurement was taken at age 30. The total height was measured for each tree, but the crown class was not determined. The records indicated if a tree had a fusiform rust stem gall or branch gall at each remeasurement.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] This research was supported by the Southern Forest Growth Trends Study of the National Vegetation Survey.

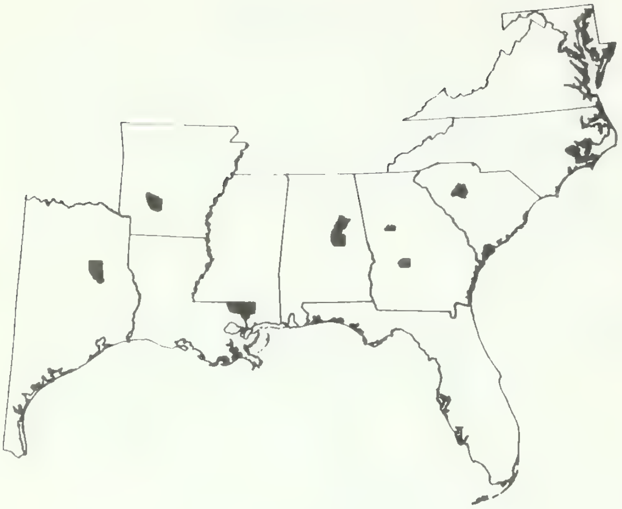

Figure 1.--The darkened areas indicate the locations of the plantations analyzed.

If two-thirds of the trees on the plot were damaged a code was associated with the plot to indicate the type of damage. The interval in which the damage occurred was not recorded, resulting in only one damage record for all growth intervals. The plots were thinned at the most twice and generally once. The thinnings were usually light, averaging approximately 13 ft^2/acre with a maximum of 40 ft^2/acre being removed. Each plantation contained at least one local seed source, which was used in this analysis. A local seed source is defined in this paper as a seed source that originated from within one degree latitude or longitude of a plantation's location.

THE ANALYSIS

Age is completely confounded with time in the data set, making inference on changes in growth through time impossible. However, the data does offer the opportunity to compare growth rates of trees grown through the same time period for several locations in the natural range of loblolly pine.

The Population

Only the local seed sources were used in the analysis for two reasons: to maximize the relevance of the analysis to the natural forest and to maximize the interpretability of the results. Growth declines have only been detected in stands that have arisen naturally. Also, the effect of moving a seed source to an environment to which it is poorly adapted to could be confounded with other growth reducing agents. By using only the local seed sources, masking of an effect or the detection of a false effect was prevented. The damaged plots were also removed from the analysis to prevent a confounding of reduced growth rates with damage. This resulted in a total of 177 growth observations from 11 locations (table 1).

Table 1.--Number of plantations, plots, and observations by location

County or Parish	Plantations	Plots	Observations
WORCESTER, MD	1	3	9
CRAVEN, NC	3	14	56
NEWBERRY, SC	1	2	6
DOOLY, GA	1	4	16
SPALDING, GA	1	3	12
COOSA, AL	1	4	12
TALLADEGA, AL	1	2	6
PEARL RIVER, MS	1	1	4
WASHINGTON, LA	2	7	28
CHEROKEE, TX	1	2	4
CLARK, AR	2	6	24
TOTAL	15	48	177

Plot Level Variables

Site index curves for each location were developed from top height because crown class was not recorded. Top height was defined as the average of the first quartile of tree heights at each plot remeasurement. All other variables were expanded to a per acre basis.

The dependent variable was the natural logarithm of annual survivor basal area growth. The difference in basal area between two times on a remeasured fixed-area plot consists of two components, survivor growth and mortality. Survivor basal area growth was used for two reasons. It is a good indicator of vigor, and it removes the need to model the complex process of mortality with a relatively low number of observations. The data was annualized by dividing total growth in a period by the period length because not all growth intervals were equal in length. The natural logarithm of the annual survivor basal area growth was used to homogenize the variance.

Stand Level Covariates

The stand level covariate model was constructed in a stepwise manner. The inverse of age was first introduced into the model. The inverse was used to model the decreasing growth rate with age. Next the natural logarithm of the initial basal area of a growth interval was included to represent the affect of density. The natural logarithm of initial basal area was later centered about its grand mean to remedy multicollinearity. Site index was next introduced to the model to represent site quality. Finally a mortality component, the proportion of initial basal area mortality during the growth period, was introduced into the model. This resulted in the site index becoming insignificant ($p = 0.82$) and being removed from the model as a concomitant variable. Concomitant variables to represent the affect of fusiform rust and thinning were examined but were found to be insignificant. Interactions between covariates were examined, but the addition of interaction terms did not improve the model and were not included.

Introducing the Affect of Climate

Due to the wide range of locations it was necessary to adjust for climatic factors that would influence growth. To determine which climatic variables would be significant in the covariance analysis it was decided to perform a tree ring analysis because this was where the influence of climate could be easily discerned. Based on the results, the significant climate variables were introduced into the stand level model to ascertain the relationship of these variables to survivor annual basal area growth.

Tree Ring Analysis.--A total of 28 cores were examined from a natural even-aged longleaf pine (*P. palustris* Mill.) stand from the Forest Service's Escambia Experimental Forest in Escambia County, Florida. Although the cores came from a different species and location than the plots used in the analysis, it was felt that these cores could be used to indicate which climatic variables would be useful in the covariance analysis. The years the cores covered were from 1960 to 1983.

A dynamic model for the analysis of the affect of climate on tree ring width (Van Deusen and Koretz 1988) was used for the comparison of climatic variables. The climate variables examined were unweighted mean precipitation, unweighted mean temperature, Palmer Drought Severity Index (PDSI), Palmer Drought Hydrologic Index, Z-Index, and the Drought Index for Southern Pines (DISP). All but the DISP variable were taken from the records of the National Oceanographic and Atmospheric Administration (NOAA) climatic division within which the Escambia Experimental Forest is located. Unweighted temperature and precipitation are the unweighted means for weather stations within a climatic division. The DISP variable was calculated from the DISP software[4]. The monthly values and their sums over a year were examined for each year. The relationship of present and previous year values for all variables to ring width and annual basal area growth were examined. The resulting two best variables were found to be PDSI and DISP. The present year's sum of monthly values performed as well as any of the monthly values. The sums were used in the covariance model due to the likelihood of the sums being robust to extrapolation (figs. 2A,B).

Table 2.--The performance of the climate variables when added to the stand level covariance model, with improving performance from top to bottom

Variable	Parameter Estimate	Significance	R-Square	MSE
Maximum DISP	0.0190	0.9203	0.6534	0.0642
Maximum PDSI	0.0010	0.4291	0.6547	0.0639
Sum of DISP	0.0340	0.1023	0.6588	0.0632
Mean DISP	0.3612	0.0209	0.6640	0.0622
Mean PDSI	0.0040	0.0125	0.6658	0.0619
Minimum DISP	0.3234	0.0054	0.6687	0.0613
Sum of PDSI	0.0008	0.0049	0.6691	0.0613
Minimum PDSI	0.0053	0.0002	0.6797	0.0595

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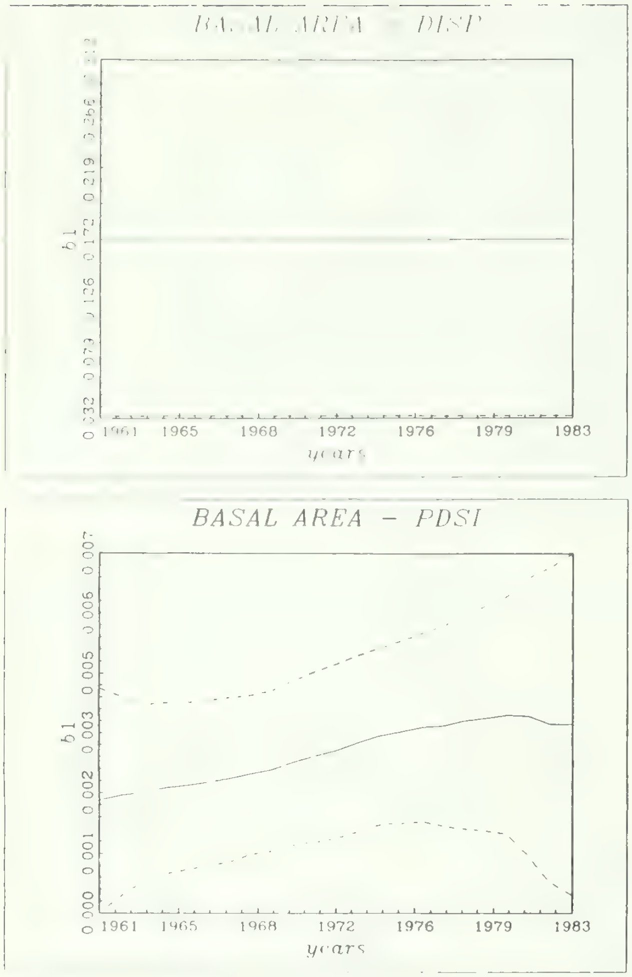
[4] The DISP model and associated software were developed by Robert Zahner of Clemson University in cooperation with the Southern Forest Growth Trends Study and are based on the PDSI for NOAA climatic divisions. The author would also like to thank Dr. Zahner for providing the tree cores used in the analysis.



Figures 2 A & B.--The solid line indicates the parameter estimates for each year and the dashed lines are the 95 percent confidence intervals. (A), parameter estimates of DISP are constant through time; (B), estimates of PDSI vary through time.

Climate Covariates--The minimum, maximum, sum and mean of the yearly values of PDSI and DISP for each growth interval were calculated and introduced independently into the stand variable model. As can be seen in table 2, the best climate variable for improving the regression was the minimum value for PDSI in each growth period. The poorest performers were the maximum values in each growth period for both variables. The means and sums varied in their performance. Based on these results it was clear that the year that introduced the greatest drought stress had the greatest influence on growth. The nonsignificance of the maximum values further substantiated this conclusion. The means and sums were moderate performers due to the summation of wet years, with dry years masking the affect of drought. The minimum PDSI was used in the final analysis combined with the stand level covariates (table 3).

Table 3.--Final covariate model and statistics

Variable	Estimate	Significance
Intercept	0.791853	0.0001
Inverse Age	17.314123	0.0001
Log Residual Basal Area	0.448923	0.0001
Proportion Basal Area Mortality	-1.289840	0.0001
Minimum PDSI	0.005380	0.0002
Adjusted R-Square = 0.6797		MSE=0.0594

ATMOSPHERIC DEPOSITION AND THE EQUALITY OF SLOPES

To perform a valid covariance analysis the equality of slopes assumption at each location for all covariates had to be tested. The relationship of a covariate to annual survivor basal area growth could vary at different locations due to some factor not accounted for in the model. This analysis could also provide information as to the role of atmospheric deposition on growth.

Scenarios of Atmospheric Deposition

The analysis is intended to detect differences in growth rates by location and indirectly evaluate the possible role of atmospheric deposition relative to other factors that may alter growth rates. The detection of atmospheric deposition as a factor in growth declines had to be determined indirectly because pollution variables were unavailable. This required that some criteria be established by which the results of the analysis could be interpreted to infer if pollutants could have played a role in differing growth rates.

Three scenarios were considered to determine what the results of the analysis would indicate relative to pollution. The three scenarios were: (1) no pollution at any of the locations, (2) equal levels of pollution at all locations, and (3) unequal levels of pollution at some or all locations. Scenario 1 served as the null hypothesis and scenario 3 served as the most likely alternative hypothesis.

Under scenario 1, the null hypothesis,

significantly different slopes were expected at some locations due to the different genetic stock and sites that were being compared. Under scenario 2, significantly different slopes were expected at some or all locations. However, it was hypothesized there would be a greater number of interactions and the interaction parameter estimates would be larger than under the null hypothesis. This would be due to differences in susceptibility of a genetic stock to pollution, or a genetics-pollution interaction. Finally, under scenario 3, a "maximum" number of interaction terms with larger parameter estimates for the interaction between location and covariate were expected due to varying levels of pollution combined with the other influences of genetics and environment.

In the same manner that genetic stock was expected to differ in its susceptibility to atmospheric deposition, a particular covariate or subset of covariates could differ in sensitivity to atmospheric deposition. This would result in the sensitive covariates having significant interaction in locations of suspected atmospheric deposition influence. Finally, the resulting interaction terms would result in a reduction in growth relative to areas hypothesized to have little or no pollution.

The testing of the equality of slopes assumption is the most important step of the analysis for any inference on the role of atmospheric deposition. Also of importance is not only whether these interactions are present but also their nature and trends.

The Analysis of Separate Slopes

Due to low sample size and multicollinearity only 6 locations could be examined for interaction terms, resulting in a sample size of 148. The locations used in the analysis of separate slopes had at least 12 observations at each location (table 1). These locations were representative of the most productive regions of loblolly pine. The analysis of separate slopes resulted in the detection of three significant interaction terms for three different covariates at three different locations (tables 4, 5). The interaction terms were positive in two locations and negative in one location. The logarithm of residual basal area interaction term at the Craven County, North Carolina, location resulted in a greater basal area growth rate for initial basal areas greater 115 ft^2/acre and lower growth rates for initial basal areas less than 115 ft^2/acre. In Washington Parish, Louisiana, the minimum PDSI interaction was positive indicating a greater sensitivity to climatic factors. There was below average growth when PDSI was less than zero, and above average growth when PDSI was greater than zero. The only interaction term that had a negative coefficient was in Clark County, Arkansas. The covariate that had a significant interaction was the proportion of basal area mortality during the growth period. This term resulted in a reduction in growth rates from the average when mortality was greater than 3 to 5 percent.

Table 4.--Relevant statistics for analysis of separate slopes

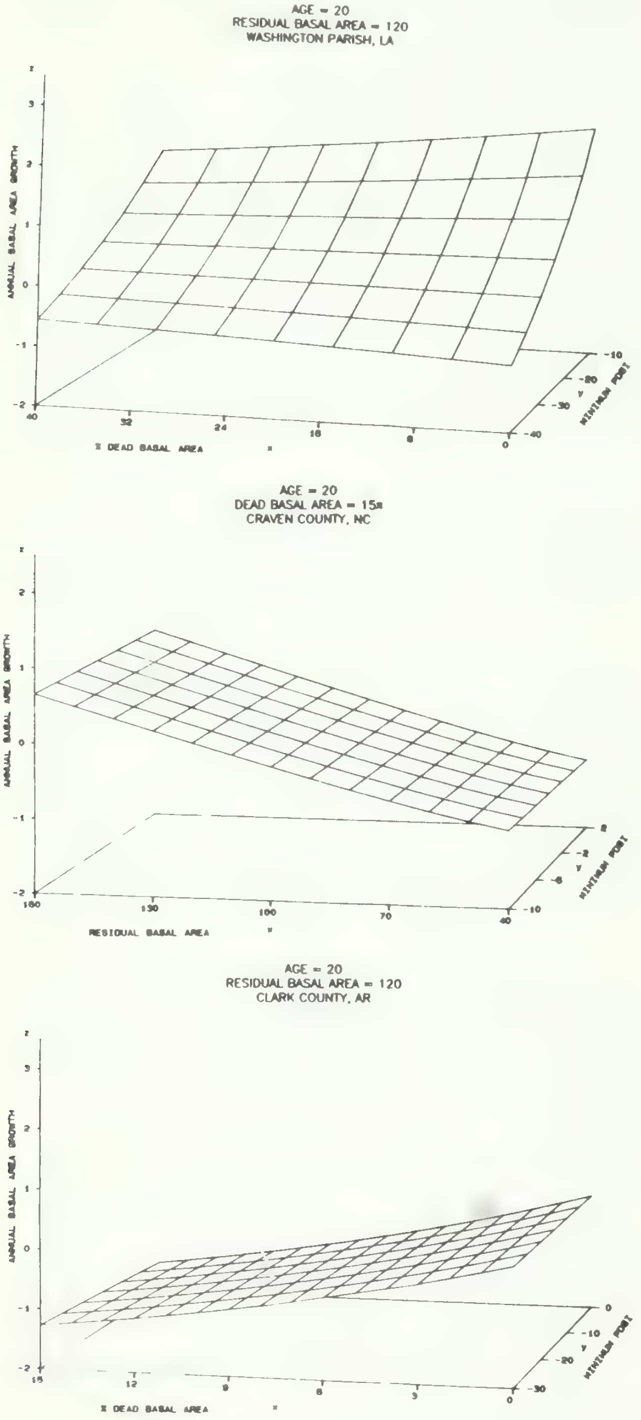
Model	Sum of Square Error	Degrees of Freedom
Separate Slopes	5.22510923	118
Equal Slopes	7.86328328	138

F = 2.97 D.F. = (20/118) Significance > 0.001

Table 5.--Significant interaction terms for analysis of separate slopes

Variable	Location	Parameter	Significance
Log of Residual Basal Area	Craven, NC	0.4425	0.0106
Minimum PDSI	Washington, LA	0.0161	0.0017
Proportion Basal Area Mortality	Clark, AR	-2.8972	0.0418

Due to the inequality of slopes, the data was further analyzed graphically to compare the differences in growth rates for the locations with interaction terms. Examples are given in figure 3. The ranges for each variable by location were used to create the graphs. In figure 3, the annual basal area growth rates for locations with interaction terms differed from the average growth rate from approximately 3 ft^2/acre greater than average to 1 ft^2/acre less than average. In the Washington Parish, Louisiana, location (fig. 3A) the growth was extremely high for moderate drought conditions but became less than average during extreme droughts. It should be noted that the local seed source in Washington Parish was from Livingston Parish, Louisiana. The Craven County, North Carolina, location (fig. 3B) is a good example of the sensitivity between residual basal area and climate. During years of extreme drought it was necesary to have high residual basal areas, approximately 115 ft^2/acre, to maintain an average growth rate, while under average moisture conditions it was necessary to have only 70 ft^2/acre of initial basal area. Finally, in the Clark County, Arkansas, location (fig. 3C) the annual basal area growth rate was consistently below average except when moisture conditions were average or better and very little mortality occurred during a growth period.



Figures 3 A, B & C.-- Growth rates for all locations with interaction terms. (A), Washington Parish, Louisiana; (B), Craven County, NC; (C), Clark County, AR.

Although the interaction terms from these locations result in below average growth, they can also result in above average growth depending on the level of the covariates. The declines in growth in Clark County, Arkansas, where a relatively constant growth decline is indicated, can be explained as easily by the presence of disease as by any anthropogenic influence.

CONCLUSIONS

Previous analyses of changes in growth rates by regression techniques have not accounted for the affect of the climate on growth. First, it is shown that indexes of drought and moisture deficit such as PDSI and DISP are climatic variables that can be used to adjust for the influence of climate on basal area growth rates. Second, it is shown that the magnitude of the maximum drought experienced during a growth interval was the best correlated climatic variable to account for changes in growth rates for growth intervals averaging 5 years in length. This indicates a need for a better understanding of the threshold values of moisture as a limiting growth factor to improve growth models that must account for the influence of climate.

It is argued that, because the affect of atmospheric deposition on stand growth cannot be analyzed by direct statistical analysis due to the lack of measurements on atmospheric depositants, only indirect inference is possible. A series of hypotheses based on the interaction of covariates by location were used to make inference on atmospheric depositants a factor in decreased stand growth rates.

Three interaction terms were detected in the analysis of separate slopes by location of annual survivor basal area growth. These interaction terms resulted in a consistently lower growth rate in one location and greater than average or less than average growth, based on the stand and climatic conditions, in the other two locations. However, the number, direction, and variables involved in the interactions were not consistent or of a magnitude that would be expected beyond natural variability. It was concluded that the form of the interaction terms estimated in the analysis of separate slopes were representative of what would be expected under scenario 1, the null hypothesis, where atmospheric deposition was not playing a widespread role on annual survivor basal area growth rates for loblolly pine.

The analysis was conducted with relatively few observations for such a wide range of locations. Although the results are indicative of differences in growth rates by location due to natural reasons, they are not conclusive in establishing the cause of the interaction terms detected.

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THE EFFECTS OF SOLUTION pH AND ANION COMPOSITION ON LEACHING OF UPLAND FOREST SOILS[1]

Laurin Wheeler[2]
Edwin R. Lawson

Abstract.--Soil cores were collected from three soils of the Springfield Plateau and the Boston Mountains of Northwest Arkansas. Soil cores were leached weekly with 4.7 cm of solution for 40 weeks. The cores received a solution with a pH of either 4.0 or 5.2. The salt content was approximately equal between solutions. Nitrate was the dominant anion in the leachate throughout the experiment. Nitrate was produced by nitrification. There was no difference between soils or solution pH. Two soils were net absorbers of sulfate. There was greater leaching of Na, Mn and K from soils that received the acid solution. The leaching of Mn, Al and Ca differed between soils.

INTRODUCTION

Acidic deposition is formed from the products of fossil fuel combustion. These products, primarily SO_2 or oxides of nitrogen (NO_x), react in the atmosphere to form sulfuric and nitric acids, both strong acids which may enter forest ecosystems as either dry fallout or acid rain or both. In systems with deficient soil levels of nitrogen or sulfur, the initial reaction of a forest may in fact be an increase in growth (Abrahamsen cited by Cowling and Linthurst 1981; Environmental Resources Limited 1983). The long term effects of acidic deposition are likely to be more dire.

Acidic deposition has been associated with a general decline in forest ecosystems in both western Europe and eastern North America. However, there is no clear agreement that the acidic deposition is responsible for the forest decline. There is equal uncertainty about the ways in which acid deposition might be deleterious to forests (Cowling and Linthurst 1981; Environmental Resources Limited 1983; McLaughlin 1984). Never-the-less, there are a number of potential ways in which acidic deposition can be detrimental to forests, either directly to the trees or indirectly by altering ecosystem processes such as mineral cycles. The expected action of acid deposition can be categorized broadly as follows:

1- A change in those processes which are affected by increased acidity such as (a) a decline in litter decomposition (Klein 1984) or (b) an increase in the solubility to toxic levels of metals such as aluminum.

2- An increase in leaching of essential nutrients, which creates a deficiency of elements such as calcium, potassium, manganese, etc. (Abrahamsen cited by Loucks 1984; Cowling and

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Linthurst 1981; Hauhs and Wright 1986; Huettl 1986; Johnson and Todd 1983; McLaughlin 1984).

Metals such as aluminum and perhaps lead and cadmium become more soluble and hence available as the soil pH declines in soils with low amounts of base cations. Eventually a concentration is reached that is toxic to fine roots. As the fine roots die, the tree´s ability to absorb water is impaired, predisposing it to top die-back or death from drought (Hauhs and Wright 1986; Huettl 1986).

The increased leaching is caused, at least in part, by increased anion loading. As the anions, which are generally weakly retained in soil, are leached downward, they are accompanied by cations so that an electrical balance is maintained within the soil (Johnson and Todd 1983). Huete and McColl (1984) found that the degree of cation varied with anion composition at constant pH. The differential mobility and consequent cation leaching between NO_3^- and SO_4^{2-} is a function of the binding capacity of SO_4^{2-} in the different soils in the Huete and McColl study.

Forest soils of much of Arkansas are weathered with low base saturation and are considered to be at risk to acid deposition (Anonymous 1985, Beasley 1986). The objective of this study was to compare the effects of simulated acid rain (pH ca. 4.0) and "normal" rain (pH ca. 5.2) on the leaching and movement of nutrients in three upland forest soils of Northwest Arkansas.

MATERIALS AND METHODS

Soil cores were collected from four upland forested sites in the Boston Mountains and Springfield Plateau of Northwest Arkansas. Three soils were selected, based on previous work, to cover the expected range in native soil pH and to give a range in fertility (table 1). One soil, the Leadvale, was collected from two locations on adjacent watersheds. Four cores were collected at each site.

A steel sleeve was turned from a pipe such that a 15 cm section of 3.5 inch (8.2 cm id) PVC pipe would fit snugly inside and rest on a lip at the bottom. The bottom was tapered, from outside to inside, to form a cutting edge. The sleeve was fitted with a removable, steel cap to protect the core while collecting. To collect a core sample, a 15 cm section of PVC pipe was placed inside the sleeve, the cap placed on the sleeve, and the sleeve driven through the litter into the soil to a depth sufficient to collect a 10 cm core. The pipe and core were removed from the soil and placed in plastic bags for transport to the laboratory. A small section of plastic screening was placed on the bottom of the cores. The cores were then mounted on plexiglas with silicone glue over a small hole.

Table 1.--The chemical properties of the soils used in the study

Property	Soil Type Allegheny	 Nixa	 Leadvale[1] (a)	 (b)
pH	5.7	4.9	5.3	5.1
	ppm			
Al	12	11	6	7
Fe	113	30	53	25
Mn	130	67	100	50
Ca	1090	250	380	220
Mg	7	68	10	23
Na	12	13	11	10
K	140	90	150	115
N	1720	1070	1500	870

[1] The Leadvale samples was collected from adjacent watersheds.

The cores received 4.7 cm (248 gm) of solution weekly. The first four weeks the cores received distilled water to allow for a period of equilibration. Thereafter, cores received either an acid rain (pH 4.0) or a "non-acid" rain (pH 5.2). With the exception of NO_3^- and SO_4^{2-}, both solutions had ionic strength and concentration similar to that for rainfall found by Wagner and Steele (1982) for Northwest Arkansas. The solutions had a NO_3^- to SO_4^{2-} ratio of 2:1 (meq:meq) for 10 weeks. The ratio was reversed for the remainder of the experiment. The time when the solutions were changed are indicated with vertical bars on graphs. The experiment had two replicates.

The leachate was collected and weighed, pH determined, and the concentration of Al^{3+} Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe^{3+}, Mn^{3+}, Cl^-, NO_3^-, NH_4^+, SO_4^{2-} estimated. Ammonium was determined by steam distillation (Bremner 1965) and titration, the remaining cations by atomic absorption spectroscopy, and the anions by reversed-phase ion-pair chromatrography (Perrone and Gant 1984, 1985).

The data presented has been adjusted for input amounts of a given cation or anion. Statistical analyses were made with Procedure GLM (SAS Institute 1985a) and graphs were prepared with SAS/GRAPH (SAS Institute 1985b). A significance level of 5% was used with all tests.

RESULTS AND DISCUSSIONS

Nitrate was the dominant anion in the soil leachate throughout the experiment (table 2; fig. 1). Freiesleben and Rasmussen (1986) also found that NO_3^- dominated the leachate. In their work as in this one, the NO_3^- was produced in situ from nitrification. There were no differences in nitrate production between rain type or soils. There was no difference in the net loss of SO_4^{2-} with acid or non-acid rain. Both the Allegheny and Nixa had net losses of SO_4^{2-} (table 3). The apparent net SO_4^{2-} adsorption in the Leadvale samples were not significantly different from zero. Chloride had no distinct patterns between solutions or soils, and the net flux of Cl^- was not detectably different from zero.

Table2.--The net gain or loss of ions from soil cores by solution type after forty weeks of leaching

Ion Leached	Solution[1] Acid Rain	Rain
	------ mg	------
NO_3^-	270	260
SO_4^{2-}	3.1	4.7
Cl^-	1.5	-0.2
Fe^{3+}	0.6	0.5
Al^{3+}	1.7	1.3
Na^+	0.6^a	-0.1^b
Mn^{2+}	1.7^a	1.0^a
K^+	27^a	16^b
H^+	-0.44^a	0.06^b
Ca^{2+}	57	56
Mg^{2+}	14	15

[1] Treatmeans with different superscripts are different at the 5% level of probability.

Contrary to our expectations, neither Fe^{3+} nor Al^{3+} had greater solubility and leaching with the acid rain (table 2). Iron, Al^{3+} and Na^+ differed from the other cations in that they had the greatest leaching during the first four weeks with distilled water (figs. 2 and 3). The leaching pattern for Fe^{3+} was very similar to that for Al^{3+}, but it was consistently about one half of it. We have seen this same response for these two cations in other experiments, and it was probably related to disturbance in taking the core rather than to the leaching solution.

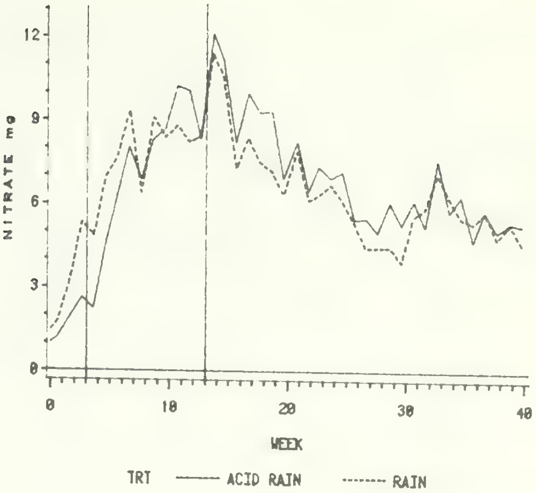

Figure 1.--The weekly leaching loss of nitrate from cores. See text for meaning of bars.

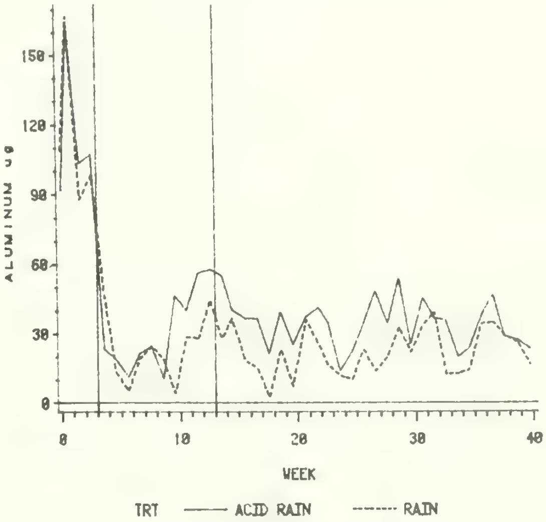

Figure 2.--The weekly leaching loss of aluminum from cores.

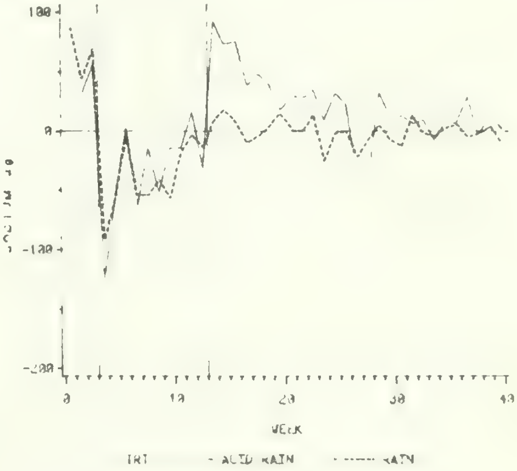

Figure 3.--The weekly leaching loss of sodium from cores.

Table 3.--The net loss of nutrients from soil cores by soil type after forty weeks of leaching

Ion Leached	Soil[1]			
	Allegheny	Nixa	Leadvale (a)	Leadvale (b)
	mg			
NO_3^-	280	320	240	220
SO_4^{2-}	11^a	11^a	-3^b	-4^b
Cl^-	-0.2	2.0	-2.8	3.6
Fe^{3+}	0.5	0.5	0.4	0.8
Al^{3+}	0.9^a	2.2^b	0.8^a	2.1^b
Na^+	0.0^a	0.6^b	0.0^a	0.4^b
Mn^{3+}	0.5^a	2.9^b	0.6^a	1.2^b
K^+	15	15	25	30
H^+	-0.30^a	-0.07^c	-0.21^{ab}	-0.16^{bc}
Ca^{2+}	79^a	68^a	41^b	39^b
Mg^{2+}	13	18	16	10

[1] Treatmeans with different superscripts are different at the 5% level of probability.

Sodium differed from all cations in that it showed a different pattern for leaching with each solution (fig. 3). The greatest amount occurred with the distilled water. There was net absorption from both types of rainfall when NO_3^- was the dominant anion. This was followed by a net loss of Na^+ for the acid rain when the solutions were dominated by SO_4^{2-}. The normal rain showed no net change for the third solution.

Manganese, and K^+ both showed greater leaching from the acid rain solution (table 2, fig. 4 and 5). The leaching curves clearly separated when the first acid solution was applied or soon thereafter. The maximum rate of leaching for K^+ occurred about the tenth week and for Mn^{3+} about the twelth week. The amounts of each element leached declined gradually thereafter. Potassium leaching declined in the normal rain when the solution was changed to one dominated by SO_4^{2-} (fig. 3).

Hydrogen also had differing absorption for the acid rain with varing NO_3^- to SO_4^{2-} ratios. The absorption rate increased by about 50% when the acid rain was dominated by SO_4^{2-} (fig. 6). There was a net production of H^+, albeit slight, in the cores leached with the normal rain. There was a net adsorption of about .38 meq of H^+ (-0.44 mg -0.06

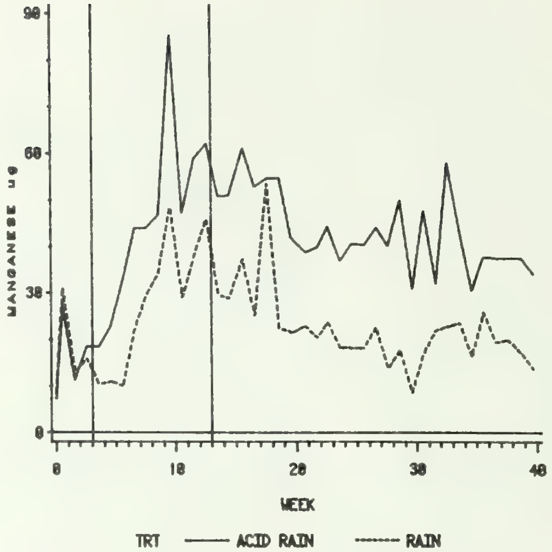

Figure 4.--The weekly leaching loss of manganese from cores.

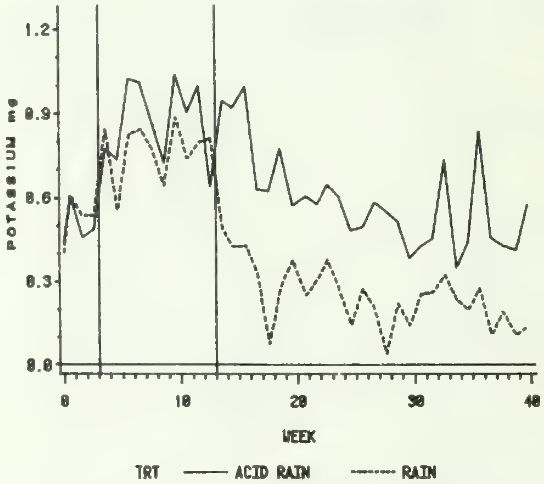

Figure 5.--The weekly leaching loss of potassium from cores.

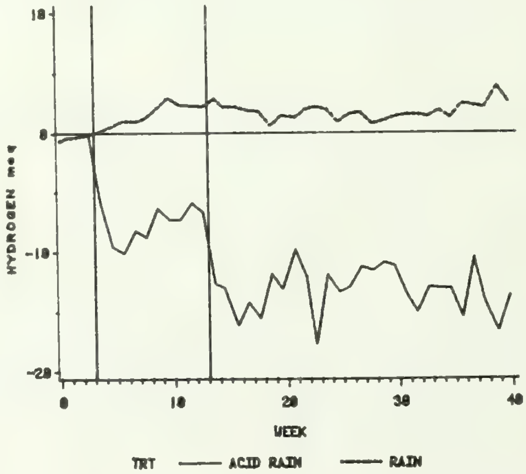

Figure 6.--The weekly leaching loss of hydrogen from cores.

mg) in the cores that received acid rain. This is very close to the net loss of 0.34 meg for Mn^{3+}, Na^+ and K^+. The increased leaching of Mn^{3+}, Na^+ and K^+ by the acid rain was a function of substitution by H^+ followed by removal from the core.

The ratio of NO_3^- to SO_4^{2-} had no effect on the leaching of H^+ with non-acid rain solutions. Neither Ca^{2+} nor Mg^{2+} had a difference in leaching between acid or normal rains with different anion ratios. Calcium leaching appeared to be closely related to NO_3^- leaching (fig. 1 and 7). The graphs for the two ions are nearly identical. The graph for Mg^{2+} (not shown) was also similar to NO_3^-.

Aluminum, Mn^{3+} and Na^+ had the same leaching pattern between soils (table 3). The quantity of each element leached was not significantly different from zero for the Allegheny or one of the Leadvale (a) samples. The amount of each element removed was significantly different for the Nixa and the second Leadvale (b) soils. Calcium had a different leaching pattern. There were significant quantities leached from all samples, but the amounts leached from the Allegheny and Nixa were about twice that from the Leadvale (table 3). While significant quantities of K^+ and Mg^{2+} were leached from the cores, there were no detectable differences between soils. Lastly, there were no significant interactions between soil type and acidity of leaching solution.

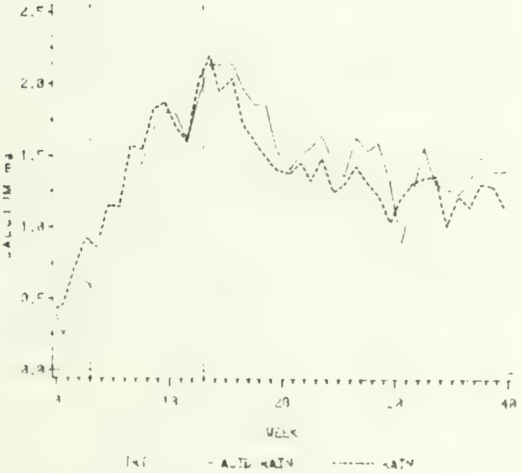

Figure 7.--The weekly leaching loss of calcium from cores.

CONCLUSIONS

Nitrate, which was the dominant anion in the leachate, was produced internally from nitrification. The greater quantities of NO_3^- increased the the movement of Ca^{2+} and Mg^{2+}. The rate of nitrification was unaffected by the pH of the leaching solution. The amount of NO_3^- produced may have been sufficient to mask the effect of solution pH, or that of anion composition.

None of the soils in this experiment had net adsorption of SO_4^{2-}. Potassium leaching declined in the non-acid rain when SO_4^{2-} was the dominant anion. Hydrogen retention was greater in acid rain when SO_4^{2-} was the dominant anion. Neither the leaching of Fe^{3+} nor Al^{3+} was affected by the pH of the leaching solution. Manganese, Na^+, and K^+ all had higher leaching rates in acid rain. There appeared to be a simple substitution of H^+ for these three cations.

The differences in leaching patterns within soils were as great as that between soils. The Allegheny and one sample of the Leadvale(a) had no net leaching of Al^{3+}, Mn^{3+} or Na^+, while the second sample of the Leadvale(b) and the Nixa had net losses of these cations. The Leadvale had no net SO_4^{2-} loss, while the Allegheny and Nixa did. All soils lost Ca^{2+}, but the Allegheny and Nixa lost about twice as much as the Leadvale.

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ATMOSPHERIC DEPOSITION EFFECTS ON LOBLOLLY PINE:
DEVELOPMENT OF AN INTENSIVE FIELD RESEARCH SITE[1]

A.H. Chappelka, B.G. Lockaby, R.S. Meldahl, and J.S. Kush[2]

Abstract.--As part of a 5-year project (1987-1991) initiated through the Southern Commercial Forest Research Cooperative, the School of Forestry at Auburn University has developed an intensive field research site to study the effects of acidic precipitation and ozone on loblolly pine growing in the Coastal Plain of Alabama. Two half-sib families differing in ozone sensitivity were planted in January, 1988 in modified open-top chambers (4.8 m x 4.5 m). Treatments included 3 levels of acidic precipitation and 4 ozone concentrations, and were replicated twice. Trees are grown in the chambers for 3 years, with periodic harvests to remove competitive effects. During each growing season, tree height, ground-line diameter, cumulative growth/flush, visible injury, biomass production, photosynthesis, water relations and nutrient status are assessed. Results from this study will provide valuable information on the response of loblolly pine to acidic precipitation and ozone, and a better understanding of the manner in which these pollutants might affect tree seedlings and saplings.

INTRODUCTION

Within the last 20-30 years, air pollutants toxic to plant life have become a potential threat to forest production in the United States, including the southern region (McLaughlin, 1985).

Air pollutants have been shown to cause acute, chronic and "hidden" injury (growth losses without visible symptoms), with each level becoming progressively more difficult to detect and accurately assess.

Data from 10-year remeasurements of Forest Inventory and Assessment plots in the southern United States have been interpreted to indicate the possibility of a recent, unexplained declinein the growth rate of southern pines in someportions of this region (Sheffield et al., 1985). These observations, along with reports of forest damage and growth decline in high elevation forests of the eastern U.S. and southern California, have led to an increase in public and industry concern (McLaughlin, 1985).

Several factors, such as drought, disease, hardwood competition, changes in stand age and previous use (old fields), and air pollution (primarily acidic precipitation and ozone) have been implicated as possible causal or contributing factors to these declines.

Because of the concern that regional air pollutants may be adversely affecting the health and productivity of forest trees, the U.S. Environmental Protection Agency (USEPA) and USDA Forest Service jointly sponsored the development of the Forest Response Program (FRP). The overall goal of this program is to determine the extent of damage to North American forests caused by acidic deposition, alone or in combination with other pollutants (Bartuska and Joyner, 1987). The Southern Commercial Forest Research Cooperative (SCFRC) was developed, through the FRP, in order to determine if sulfur and nitrogen deposition and associated pollutants are causing, or have the potential to cause, detrimental changes in the health and productivity of southern commercial forests.

As part of a 5-year project (1987-1991), supported by the SCFRC, 5 intensive research field sites have been established throughout the southern U.S., including sites have been located at Auburn University, Clemson University, University of Florida, Duke Forest and Stephen F. Austin Forest. The purpose of this paper is to describe the development and methodologies used in assessing the effects of acidic precipitation and ozone on growth, biomass production, nutrient status and physiological response of loblolly pine (Pinus taeda L.) seedling and saplings growing in the Coastal Plain of Alabama.

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[1] Paper presented at Southern Silvicultural Research Conference, Memphis, Tennessee, November 1-2, 1988.

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SITE DESCRIPTION

The research site is located on the Auburn University campus and has been occupied by pine forests for the last 50 years. Approximately one-half of the site (1.5 acres) was predominately loblolly pine and the remainder with longleaf pine (P. palustris Mill.). The topography of the site ranges from level to a 1-3% slope. The area is dominated by a single soil series, the Cowarts (a Typic Hapludult). The soil is moderately well drained and has a site index for loblolly pine of 80 at age 50. Both the soil characteristics and site quality of the study area may be considered typical of pine sites in the rolling Coastal Plain.

METHODOLOGIES

Site Preparation

Trees on the site were whole-tree harvested in the winter of 1986. Trees were harvested with the use of a shear and were removed prior to delimbing. Minimal skidding occurred on the site. Residual brush was cut and removed from the area. Large (>3 inches diameter) woody debris remaining from the harvesting operation, were removed by hand. In an effort to further reduce debris and sprouting of hardwood stumps, the site was broadcast burned.

An extensive soil characterization was made, which included assessment of both chemical and physical soil attributes. Included among these measurements were bulk density, soil pH, organic matter content, CEC, total N, extractable P, exchangeable K, Ca, and Mg, and concentrations of selected micronutrients.

Exposure Chambers

In order to test both acidic precipitation and ozone effects on tree growth in the field, open-top chambers (Heagle et al., 1973) with rain exclusion covers were constructed. These chambers permit control of pollutants, allowing specific treatment regimes to be imposed on the plants in dose-response experiments. The chambers are 4.8 m x 4.5 m aluminum, cylindrical frames covered with clear plastic film.

Three acidic precipitation treatments are applied in this study; 5.3, 4.3 and 3.3. These levels were chosen to span the average pH of rainfall in the southern U.S. Acidic solutions are prepared by adjusting the pH of deionized water containing selected background ions (Shafer et al., 1985) with a 1 N mixture of sulfuric and nitric acids (70 meg SO_4^{-2}:30 meg NO_3^{-1}). Simulated rain is applied through a stainless steel solid cone nozzle mounted on a bracket at the top of each chamber. Rain is applied twice weekly in the chambers, based on 30-year monthly rainfall averages for the Auburn area.

Four ozone treatments are employed in this experiment: chambers to which air is filtered through charcoal before entering enclosures to remove ambient ozone; chambers to which ambient air is supplied; and chambers where ambient air is supplemented with two concentrations (1.7X and 2.5X, respectively) of ozone applied proportionally above ambient. Ozone is added 12 hours a day (0900-2100 h), 7 days a week. Addition during this period assures environmental conditions conducive to elevated concentrations and maximum photosynthetic activity. Ozone concentrations are monitored using an EPA-accepted instrument with a rapid response time. Instruments are calibrated periodically according to USEPA quality assurance guidelines, and audited once per year. In addition, complete meteorological data for the site are available.

Experimental Methods

Two half-sib Coastal Plain loblolly pine families were placed in the ground during the winter of 1987, and were exposed to ozone beginning in May and acidic precipitation treatments beginning in July 1988. These families are GAKR 15-23, considered to be tolerant in its sensitivity to ozone and GAKR 15-91, regarded as ozone sensitive, based on laboratory results. Twelve treatments are replicated twice in a randomized complete block design. The treatments are a factorial arrangement of the 3 levels of acidic precipitation and 4 ozone concentrations.

Trees will be grown in the chambers for 3 years, and exposed to acidic precipitation and ozone treatments during each growing season. Due to harsh environmental conditions, chamber plastics are removed, and treatments discontinued during the winter months (January - March). At the initiation of the study (spring, 1988) a total of 96 trees, 48 per family, were planted in each chamber (2304 total trees). During the 1988 growing season trees were periodically thinned until 12 trees per chamber (6 per family) will remain at the end of the 1988 growing season. At the initiation of the 1989 growing season, 4 trees per chamber will be removed, leaving 8 trees per chamber. Four trees will be harvested at the end of the 1989 season, leaving 2 trees per family, per chamber to carry through the end of the 1990 growing season. At this time all remaining trees will be harvested.

Measurements are taken according to the schedule shown in Table 1. Seedlings are measured monthly for total height and ground-line diameter. Trees were harvested periodically during the 1988 growing season at which time percent nitrogen (N) concentration and content were determined. This periodic sampling will allow N flux within developing seedlings to be followed on a component basis. In addition, abscised foliage was collected. Inclusion of component N content at several points during the growing season may allow internal translocation differences to be separated from effects induced by variation in foliar leaching. In addition to N determination during periodic harvests, above-ground biomass, chlorophyll content, leaf area and total non-structural carbohydrate contents will also be evaluated. This will facilitate the determination of the effects of acidic precipitation and ozone on patterns of carbon allocation, energy utilization and physiological status of the seedlings. At the final harvest, each growing season, above-ground biomass, carbohydrate content, and nutrient content (N, S, P, K, Ca, Mg) will be determined. Trees will also be rated for visible injury due to acidic precipitation and/or ozone.

Table 1.--Growth response variables and measurement schedule for SCFRC funded research at the Auburn Intensive Research Site

Variable	Schedule
Height	Monthly, 1988, 1989, 1990
Ground-line diameter	Monthly, 1988, 1989, 1990
Cumulative growth/flush	End of year, 1988, 1989, 1990
Visible injury	End of year, 1988, 1989, 1990
Gas exchange	Monthly, 1988, 1989, 1990
Water relations	Monthly, 1988, 1989, 1990
Leaf area	End of year, 1988, 1989, 1990
N concentration/content	Periodic harvests, 1988
Litterfall (N status)	Monthly, 1988, 1989, 1990
Nutrient status	End of year, 1988, 1989, 1990
Carbohydrate status	Periodic harvests, 1988, End of year 1989, 1990
Root biomass	End of year 1988, 1990

Root growth and biomass were determined after the 1988 growing season. In each chamber 4 trees per family were planted in 15 cm diameter polyvinyl chloride (PVC) pipes placed approximately 60-76 cm in the ground. These seedlings are harvested and pipes removed at the end of the 1988 season. This will permit sampling of complete root systems of individual seedlings, and will provide a better perspective on carbohydrate allocation and nutrient distribution.

During each growing season, monthly photosynthetic measurements will be conducted. Net CO_2 exchange, transpiration, and leaf conductance will be measured using a portable infra-red gas analyzer. Seedlings will be evaluated for water relations during pre-dawn and solar noon on a monthly basis.

In addition to these projects funded by the SCFRC, several other related studies are ongoing at the Auburn Intensive Research site (Table 2). Results obtained from research at this site will provide needed information on the response of loblolly pine to acidic precipitation and ozone and a basic understanding of mechanisms in which these pollutants affect tree seedlings and saplings.

Table 2.--Air pollution studies conducted at the Auburn Intensive Research Site funded through sources other than SCFRC

Project title	Institutions involved	Funding source
Influence of acid precipitation and ozone on loblolly pine rhizosphere chemistry	Auburn Univ., TVA, USDA Forest Service	USDA Forest Service, So. Station
Influence of acid precipitation and ozone on loblolly pine rhizosphere microorganisms	Tuskegee Univ.	USDA Forest Service, So. Station
Effects of ozone and acidic precipitation on spectral reflectance in loblolly pine	Auburn Univ., NASA	USEPA
Impact of ozone on susceptibility of loblolly pine to pitch canker disease	Auburn Univ.	USEPA
Loblolly pine growth relative to ozone pollution and antioxidant application	Auburn Univ.	Unfunded
Influence of acid precipitation and ozone on loblolly pine root growth and association with rhizoshpere chemistry and biology	Auburn Univ., TVA,USDA Forest Service	Pending

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Ecophysiology

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EFFECTS OF SHADING AND MYCORRHIZAE ON THE GROWTH AND DEVELOPMENT OF CONTAINER-GROWN BLACK AND ENGLISH OAK SEEDLINGS[1/]

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Black and English oak seedlings inoculated with Pisolithus tinctorius, Suillus luteus, Thelephora terrestris or left uninoculated were grown in Spencer LeMaire containers in greenhouse for 16 weeks, overwintered and outplanted into an old field in central Missouri. Field treatments were 100%, 70% or 37% of full sunlight. Root and stem dry weight and percentage ectomycorrhizal colonization were assessed in the fall following the first growing season. Inoculation had a greater effect on root than on stem dry weights during growth in the greenhouse, but resulted in significant increases in stem and root dry weights after only one growing season in the field. Dry weight of English oak was twice that of black oak after one field season, with a disproportionate amount of black oak growth occurring in the root system. These differences in growth may reflect differences in survival strategies between the two species.

INTRODUCTION

Colonization of tree roots by mycorrhizae-forming fungi has been shown by many investigators to be beneficial and sometimes even essential to host plant survival and growth (Schramm 1966, Dixon et al. 1981). The energy source for mycorrhizal fungi is carbohydrates obtained solely from the host plant photosynthesis (Bjorkman 1970).

Light requirements for optimal photosynthesis and growth in oak vary with species and environmental conditions. Photosynthesis (Loach 1967) and growth (Musselman and Gatherum 1969) are maximal in some oak species at less than full sunlight, while other species require full sunlight (Arend and Scholz 1969). As mycorrhizae are totally dependent upon the host plant for their food substrate (photosynthate), irrespective of the plants needs, any environmental condition, such as light regime, which will alter photosynthesis will likely influence mycorrhizal development. Moreover, inhibition of the formation of mycorrhizae will typically result in a growth reduction of oak seedlings (Garrett et al. 1979).

The objective of this study was to compare growth responses of black and English oak (Quercus velutina Lam, Q. robur L.) inoculated with three known ectomycorrhizae-forming fungi and grown under three light regimes (100%, 70% and 37% of full sunlight).

MATERIALS AND METHODS

Half-sib (open-pollinated) seed of black and English oak was collected from trees growing on the University of Missouri-Columbia campus. Acorns were surface sterilized with a 10% sodium hypochlorite solution, stratified, pre-germinated and planted in 500 ml, four-cavity Spencer LeMaire roottrainers. These containers were filled with a 1:1 (v/v) peat moss-vermiculite mixture that had been sterilized by fumigation with methyl bromide. Mycorrhizal inoculation was accomplished prior to sowing by mixing into each container cavity 25 ml of inoculum produced by the methods of Marx and Bryan (1975). All seedlings were grown in a greenhouse with day length extended to 16h with high intensity sodium lamps (giving 700 μmol m^{-2} s^{-1} at the plant tops). Day and night temperatures averaged 34 and 22C, respectively. Seedlings were watered as needed (20 ml per cavity) and fertilized biweekly with full strength Hoagland's solution (75 ml per

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Table 1.--Dry weights and percentage infections of ectomycorrhizal black and English oak after a 16-week greenhouse production period and one growing season in the field.

	Greenhouse			Field		
Ectomycorrhizal treatment	Stem dry wt.	Root dry wt.	% inf.	Stem dry wt.	Root dry wt.	% inf.
	-g-	-g-		-g-	-g-	
-English oak-						
P. tinctorius	1.30a[1]	4.34a	88a	3.82b	7.04b	69a
S. luteus	1.11a	3.04ab	84a	6.30a	10.50a	49b
T. terrestris	1.35a	2.23c	64a	5.66a	9.33a	54b
none	0.97a	2.99bc	3b	3.99b	7.85b	15c
-Black oak-						
P. tinctorius	0.52a	1.77a	85a	1.03b	5.42a	59a
S. luteus	0.56a	1.51a	30b	1.25a	4.97ab	46b
T. terrestris	0.43a	1.56a	40b	1.03b	5.04ab	39b
none	0.49a	1.59a	0c	0.90b	4.19b	9c

[1] Values followed by the same letter are not significantly different ($p \leq 0.05$).

cavity). Following a 16-week growing period, five seedlings per treatment were randomly selected for destructive growth measurements; the remainder were prepared for later outplanting.

Seedlings were planted into an old field in central Missouri during early May. Soils were of the Hatton series, slopes ranged from two to five percent and the site index (base age of 50 years) for black oak was 65. Twenty-four treatments consisting of completely crossed combinations of two oak species, three shade levels and four fungal symbionts (Pisolithus tinctorius, Suillus luteus, Thelephora terrestris) were established in a 2 x 3 x 4 factorial design and arranged in randomized complete blocks. Four blocks were established with each treatment containing six seedlings. Light treatments were created by placing a wire frame covered with Chicopee lumite polypropylene black shade fabric [63% or 30% actual shade (A. H. Hummert Seed Company, St. Louis, MO)] over the appropriate seedlings. To avoid heat buildup, the fabric was elevated slightly above the ground and a small-diameter opening was left at the top to create a "chimney draft-effect". Leaf temperature (measured with a fine-wire thermocouple) and leaf water potential (determined by a Scholander pressure chamber) measurements made during late June and July revealed no significant differences among treatments in leaf temperature or plant water balance.

Seedlings were harvested beginning September 29. Percentage ectomycorrhizal colonization was determined using standard methods (Mitchell et al. 1987) and dry weights were determined following drying at 80C for 48h. Data were analyzed by analysis of variance and treatment means were compared with Duncan's New Multiple Range test at the 95% confidence level. Percentage infection data were arcsine transformed prior to analysis.

RESULTS

Greenhouse Growth

Periodic evaluations of seedling root systems in the greenhouse revealed that ectomycorrhizal development did not occur until week 11. Daughtridge et al., (1986), while conducting a classical growth analysis on inoculated black oak, also found no visible evidence of colonization prior to week 10. At the end of 16 weeks in the greenhouse, hyphal development in the rooting medium of all inoculated containers was heavy; however, with the exception of seedlings inoculated with Pisolithus, percentage colonization was significantly lower in black than in English oak (Table 1).

Seedling growth in the greenhouse was not greatly affected by inoculation. No significant differences were observed in stem dry weights and only Pisolithus tinctorius inoculated seedlings had significantly greater root growth and then only in English oak. Total root dry weight was 45% greater for Pisolithus-inoculated than for uninoculated English oak. English oak also demonstrated superior growth in general to that of black oak. Mean seedling dry weight (exclusive of the foliage) of English oak (4.3g) was double that of black oak (2.1g).

Table 2.--The effects of light on percentage mycorrhizal colonization and dry weights of English and black oak.

	English oak			Black oak		
Light treatment	Stem dry wt.	Root dry wt.	% inf.	Stem dry wt.	Root dry wt.	% inf.
	-g-	-g-		-g-	-g-	
Full	5.18a[1]	9.45a	62a	1.11a	5.24a	39a
70%	5.40a	9.23a	44b	1.01a	5.23a	41a
37%	4.25b	7.38b	33c	1.03a	4.23b	29b

[1] Values followed by the same letter are not significantly different ($p \leq 0.05$).

Field Growth

The growth advantage held by English over black oak in the greenhouse was retained and even increased in the field. Across all treatments average stem weights of English and black oak were 4.9 and 1.1g, respectively, while root weights were 8.7 and 4.9g.

Stem and root dry weights in the field were significantly improved by inoculation. However, the fungal organism providing the greatest growth advantage under greenhouse conditions did not provide the greatest growth advantage in the field. While Pisolithus-inoculated English and black oak appeared to perform best in the greenhouse, Suillus-inoculated plants generally performed best in the field (Table 1). Moreover, this pattern was evident even though Pisolithus seedlings had a significantly higher percentage of their root systems colonized with mycorrhizae.

Decreased light intensities were a factor in dry weight produced only when shading was heavy (Table 2). A reduction from full to 70% sun elicited no significant effect in dry matter yields, although a significant decrease in percentage ectomycorrhizal infection was found in English oak across all mycorrhizal species (62 to 44%). A parallel decrease was not observed in black oak perhaps because of the unusually low infection (39%) present under full sun conditions. Significant reductions in colonization percentages were observed in both species with further decreases in light to 37%.

DISCUSSION

Greenhouse Growth

English oak seedlings produced twice the dry weight of black oak seedlings during the 16-week production period with substantially higher mycorrhizal colonization percentages. Early development of mycorrhizae on the root system of container-grown oak seedlings, however, provided little growth advantage. This is much in contrast to the findings of others which have demonstrated substantial growth benefits from container (Dixon et al. 1981, Daughtridge et al. 1986) and nursery inoculation of oak (Marx 1979a, 1979b). Marx demonstrated that in nursery plots of white and northern red oak, inoculation with Pisolithus tinctorius significantly increased heights and weights while Dixon et al. (1981) found significant increases in all phases of container-grown black oak growth including root length and leaf surface area. The lack of growth response in our study is attributed to the slow development of the mycorrhizae possibly due to over watering.

Field Growth and Development

English oak widened its growth advantage over black oak in the field by increasing its dry weight 216% compared to only 186% for black. Furthermore, contrasting growth patterns were observed. Black oak seedlings had relatively greater root growth while English oak allocated more of its photosynthate to stem development. This is demonstrated by changes occurring during the first year in the field of -33% and +46% in root/shoot ratios for English and black oak, respectively. While speculative in nature, this might suggest quite different survival strategies for the two species. Black oak, which is typically found growing on sites characterized by shallow soils and droughty conditions, appears to be conservative in its growth habit and emphasizes root development during its early years to enhance survival under potentially adverse conditions (Fowells 1965). English oak, on the other hand, which is more typically found growing on sites of reasonable moisture-holding capacity (Wright et al. 1973), appears to have developed a growth strategy enabling it to compete more favorably for light.

The results from our shade experiment further support this relationship. An increase in shading from 70% to 37% resulted in greater inhibition of growth in English than in black oak. Ectomycorrhizal development was also more sensitive to changes in light regimes in English oak. This could indicate greater changes in available photosynthate in shaded English than in shaded black oak. Others have reported light requirements for these species similar to those observed in this study. For example, Shaw (1974) observed that 30% full sunlight was required for English oak survival, and at least 50% was required for significant growth. Grasovsky (1929) found that black oak could survive at least ten months at light intensities between three and four percent of full sunlight, and that growth could be maintained with only moderate increases above this level.

Mycorrhizal inoculation significantly increased seedling dry weights in the field even though only slight growth improvements occurred in the greenhouse. Moreover, while Pisolithus-inoculated plants generally performed best in the greenhouse, Suillus-inoculated plants grew best under field conditions. These results emphasize the importance of selecting the best organism for the species and planting site under consideration. Garrett et al. (1979) reported that several ectomycorrhizae-forming species are available for oak, and Dixon et al. (1984) demonstrated the importance of selecting the correct symbiont for optimizing growth responses. Furthermore, Trappe (1977) stressed the need to test many species and isolates within a species, as strains differ in how they affect host metabolism. Assuming that the selection of a desirable ectomycorrhizal species and isolate is made, our research indicates that the physiological benefits can lead to increased success in regenerating oak.

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PHYSIOLOGICAL RESPONSES TO THINNING IN EIGHT-YEAR OLD LOBLOLLY PINE STANDS ON THE VIRGINIA PIEDMONT[1]

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Abstract.--The effects of thinning on needle photosynthetic rates and water potentials, as well as on whole-tree growth, were examined in eight-year-old loblolly pine stands on the Virginia Piedmont. Lower crown needle response to the sudden light increase which follows thinning was also examined. Thinning increased growth of several parameters but did not affect individual needle physiology. Lower crown and upper crown photosynthetic rates were significantly different. Lower crown needles photosynthesized at significantly higher rates than upper crown needles when both were measured in full sun light.

INTRODUCTION

Thinning has become a common practice in the management of loblolly pine (Pinus taeda L.) throughout the southeastern United States. The benefits of thinning in terms of increased growth have long been recognized.

In 1960 Della-Bianca and Dils showed that 37-year-old red pine (Pinus resinosa Ait.) stands thinned to 80 sq.ft/acre of basal area grew twice as much as stands with 190 sq.ft/acre the second year after thinning. In the same year, Zahner and Whitmore presented fifth year results from a heavy thinning of loblolly pine at age nine. Areas thinned to 10 sq.ft/acre produced trees with an average of 4.3 inches of diameter growth over the five year period while trees in the unthinned areas, with 70 sq.ft/acre, grew an average of 1.9 inches in diameter over the same period. Bassett (1964) found that 30-year-old stands of loblolly pine thinned to 55 sq.ft./acre grew 3.2 inches in diameter during the four subsequent years while those thinned to 125 sq.ft./acre grew only 1.9 inches.

The benefits of thinning are clear, yet little is known about the physiological processes responsible for the increase in growth. Thinning affects the availability of moisture, nutrients and light and influences temperature within the stand. These changes certainly influence photosynthesis on a whole tree basis, but do they cause changes in the activity of individual needles?

With the above in mind, the objectives of this study were to determine changes in physiological processes which occur during the first growing season following thinning and to evaluate the relationship between these changes and the growth response to thinning. The effect of the sudden light increase which follows thinning on lower crown needles was also evaluated.

METHODS

Three replicate stands, each 0.55 acres in area, were chosen for use in this study. The trees were planted on a ten-foot by ten-foot spacing in 1980. Before thinning the average heights of the trees in the three replicates were 30.7, 26.2 and 27.3 ft and the average diameters at breast height were 6.0 inches, 5.4 inches and 5.4 inches.

On March 2, 1980, one half of each stand was chosen randomly and thinned mechanically by removing alternate, diagonal rows. Thus, half of the trees in each thinned plot were removed. The outer two rows of trees on each plot were considered border trees and were not measured for growth or for physiological changes.

Physiological measurements were made approximately biweekly beginning on April 8, 1988 and ending on September 23, 1988. Photosynthesis and xylem water potential were measured on twigs clipped from the upper and lower third of the crowns of six randomly chosen expressed as a percentage of the original value, increased more in the thinned plots than in the controls although this difference was not statistically significant.

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No significant physiological differences were observed between the trees in the thinned and in the control plots when needles from each were measured under identical conditions. The photosynthetic rates (fig 1) and water potentials (fig 2) did not differ significantly, nor were there any consistant patterns in their values throughout the summer.

Whole-tree photosynthesis, estimated using whole-tree needle surface area estimates, light extinction curves measured in each plot and light saturation curves derived for loblolly pine seedlings (Seiler, unpublished data) did differ significantly between thinned and control plots ($p < 0.02$). The average tree in the thinned plots assimilated 64 grams of carbon per hour while the value for the average control tree was 48 grams per hour.

Physiological differences were observed between needles from the upper third and the lower third of the crowns. Surprisingly, the photosynthetic rates of needles from the lower third of the crowns were consistantly, and often significantly, higher than those of needles from the upper third (fig 3). This trend was consistant from the first measurement date, April 8, until late summer. Beginning August 15 and continuing through September, upper crown needles had photosynthetic rates that were slightly higher than those of the lower crown needles.

DISCUSSION

The observed growth differences between thinned and control plots indicate that thinning immediately stimulates diameter and crown diameter growth. The reduction in height growth that followed thinning was likely due to a redistribution of photosynthate: trees in the thinned plots spent more fixed carbon expanding their crowns into the newly available light. It is also likely that they were expanding their root systems into the soil left vacant by the trees that were removed.

Thus, due to their greatly increased photosynthetic and absorptive surfaces, the trees in the thinned plots now have greater access to the resources needed for growth. This will afford them even greater growth increases in the future, possibly allowing them to grow in height enough to catch up with the control trees while continuing their accelerated diameter growth.

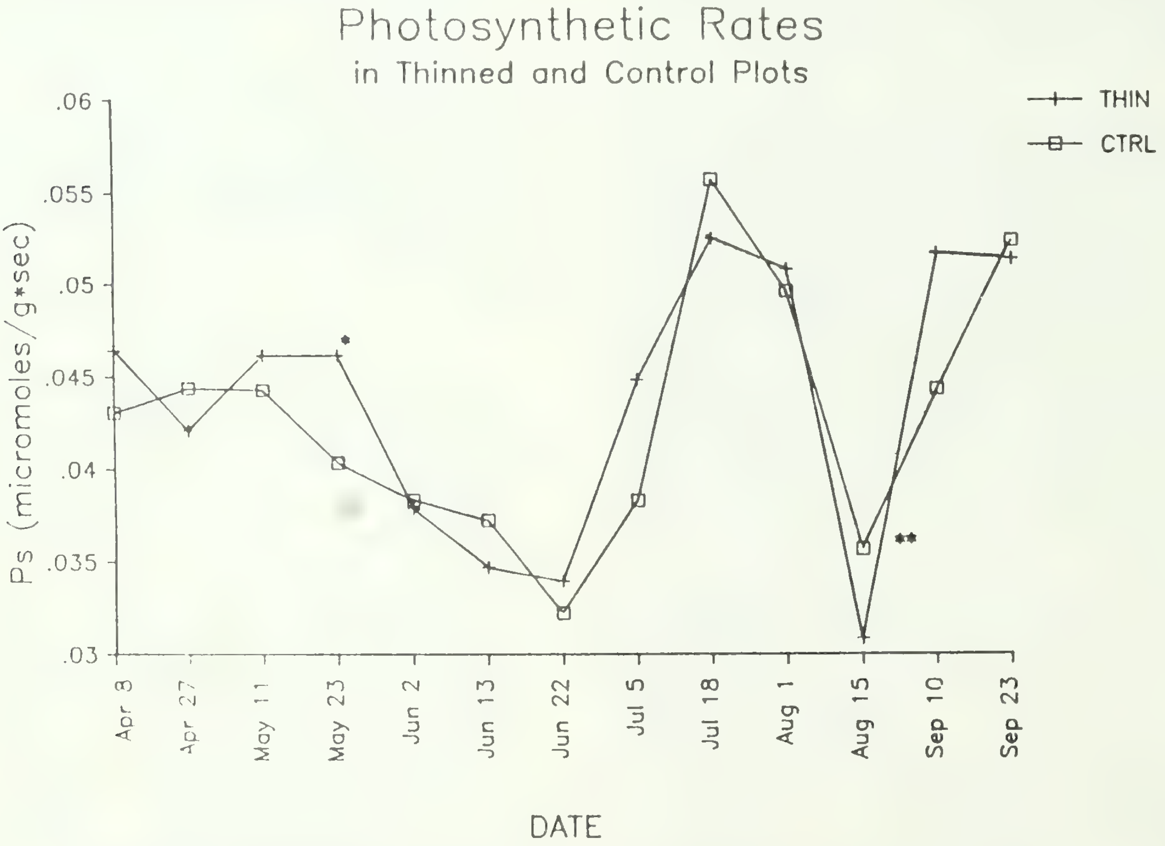

Figure 1.--Photosynthetic rates of trees in thinned and control plots through the summer of 1988.
* indicates a significant difference between treatments at alpha = 0.10;
** indicates a significant difference between treatments at alpha = 0.05.

trees in each treatment-block combination (36 trees total).

The twigs were clipped, placed in sealed plastic bags and carried to the measurement station which was set up just outside the stand where full ambient sunlight was available. Needles were removed from the twig and placed in the cuvette of the Li-Cor 6200 portable photosynthesis system (Li-Cor, Inc. Lincoln, NE) for measurement of photosynthesis. The remainder of the twig was placed in a pressure chamber (PMS Instruments, Corvallis, OR) and its water potential was measured. All measurements were made within ten minutes of the removal of the twig from the tree as preliminary measurements indicated that physiological variables did not change over this timespan when twigs were kept in plastic bags in the shade. Environmental variables--photosynthetic photon flux density, temperature, relative humidity and carbon dioxide concentration of the air--were monitored during all measurements. After each measurement, needles were removed from the Li-Cor cuvette and stored in plastic bags in a cooler for subsequent measurement of projected surface area (Li-Cor 3000, Li-Cor, Lincoln, NE) and dry weight.

Height, diameter at breast height, live crown ratio and live crown diameter (an average of two perpendicular measurements) were measured at the beginning and at the end of the growing season on all measurement trees in each treatment-block combination. These values were used to contrast growth differences between the treatments and to calculate volume and basal area in each plot.

RESULTS

Growth differences were observed between the thinned and control plots even in the first growing season following thinning (table 1). Trees in the thinned plots grew more in live crown diameter, diameter at breast height, and crown surface area and dry weight than did trees in the control plots. Trees in control plots grew more in height. This offset the death of the lower branches, resulting in no net live crown ratio change. Thinned plots grew less in height but lost fewer lower crown branches, resulting in the same negligible change in live crown ratio (table 1).

Of these results, the greater increase of live crown diameter in the thinned plots and the greater height growth and increase in height to the base of the live crown in control plots were the only statistically significant differences. Reports of other thinning studies indicate that several years of data are often needed before differences become statistically significant. Bassett (1964) reported significant results four years after thinning, Zahner and Whitmore (1960) five years after thinning, and Della-Bianca and Dils (1960) two years after thinning. Thus, the lack of statistical significance after one growing season is not surprising.

Thinning shock, a reduction in growth that is often mentioned in association with thinning (Donner and Running 1986) was not observed. Basal area and volume increases, expressed as a percentage of their original values, were essentially identical in the thinned and control plots (table 2). Needle dry weight, again

Table 1.--Individual Tree Growth During the First Growing Season Following Thinning

Measure	March		September		Growth	
	Thin	Ctrl	Thin	Ctrl	Thin	Ctrl
Height (ft)	28.7	27.4	30.9	31.8	2.2	4.5[1]
D.B.H. (in)	5.75	5.45	6.61	6.18	0.86	0.74
Cwn. Ht. (ft)	8.4	7.3	9.2	9.7	0.7	1.4[1]
Cwn. Dia. (ft)	11.3	10.7	13.9	12.3	2.6	1.6[2]
Cwn. Surf. Area (m^2)	2364	2066	3240	2736	876	670
Cwn. Dry Wt. (lbs)	35.2	30.8	48.2	40.6	13.0	10.0

1 indicates a significant difference at alpha = 0.10.
2 indicates a significant difference at alpha = 0.05.

Table 2.--Stand Growth During the First Growing Season Following Thinning

Measure	March		Growth		% Growth[1]	
	Thin	Ctrl	Thin	Ctrl	Thin	Ctrl
Volume (ft^3/acre)	522.3	884.1	210.0	427.3	47.8	49.8
Basal Area (ft^2/acre)	40.5	72.5	12.9	20.7	32.0	28.6
Dry Weight (lbs/acre)	7666	13438	2841	4346	46.1	35.2

1 Percent Growth = Growth/March x 100

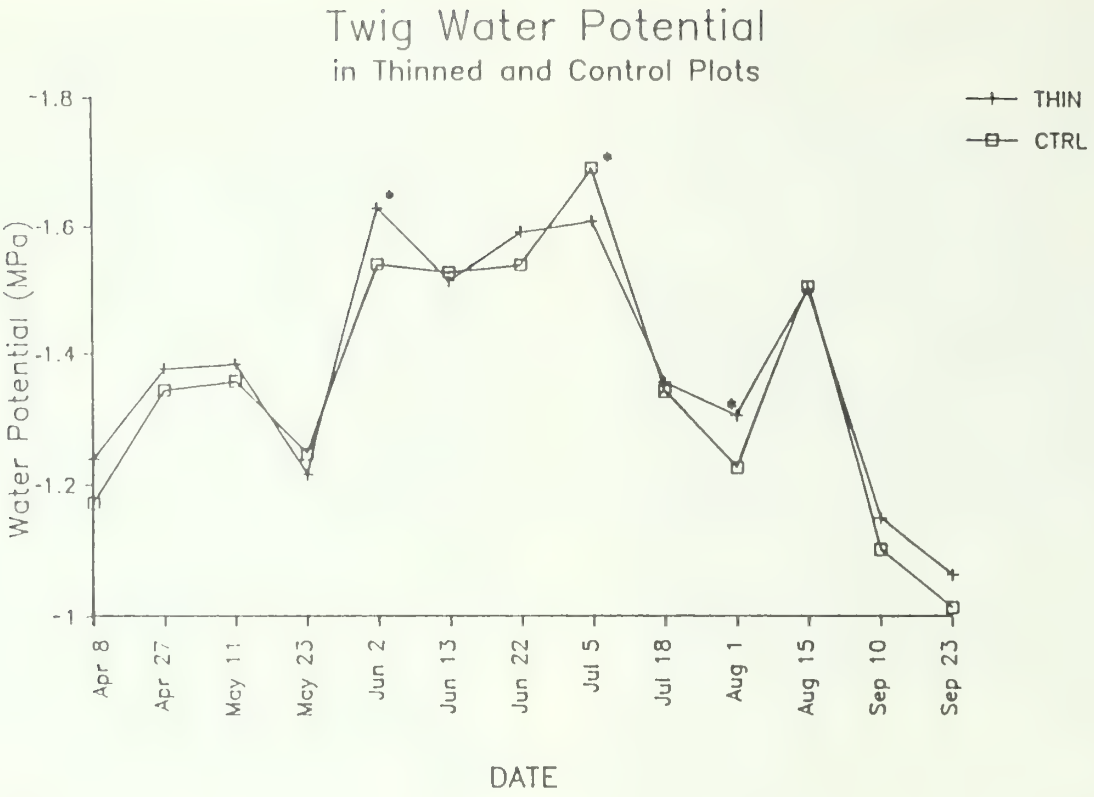

Figure 2.—Midday water potentials of trees in thinned and control plots through the summer of 1988. ✱ indicates a significant difference between treatments at alpha = 0.10.

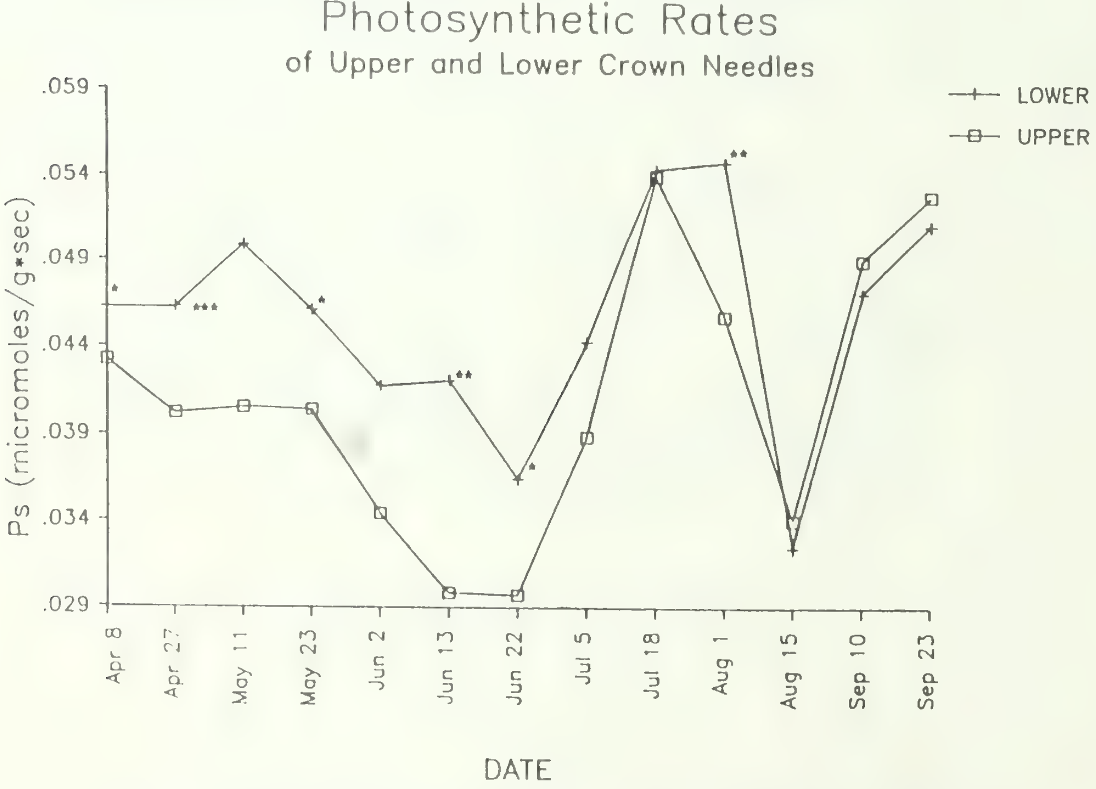

Figure 3.—Photosynthetic rates of needles in the upper and lower thirds of loblolly pine crowns through the summer of 1988. ✱ indicates a significant difference between crown positions at alpha = 0.10; ✱✱ indicates significance at alpha = 0.05; ✱✱✱ indicates significance at alpha = 0.01.

The absence of different photosynthetic rates when needles from the two treatments were measured under identical environmental conditions indicates that the observed growth differences were due merely to environmental conditions within the stand. Differences in light levels and space availability both above and below ground were the most obvious differences although temperatures and air movement likely differed as well.

It is possible that thinning does affect individual needle physiology via its effects on water potential when water becomes a limiting factor. Many other investigators (Donner and Running 1986, Moehring and Ralston 1967, Bassett

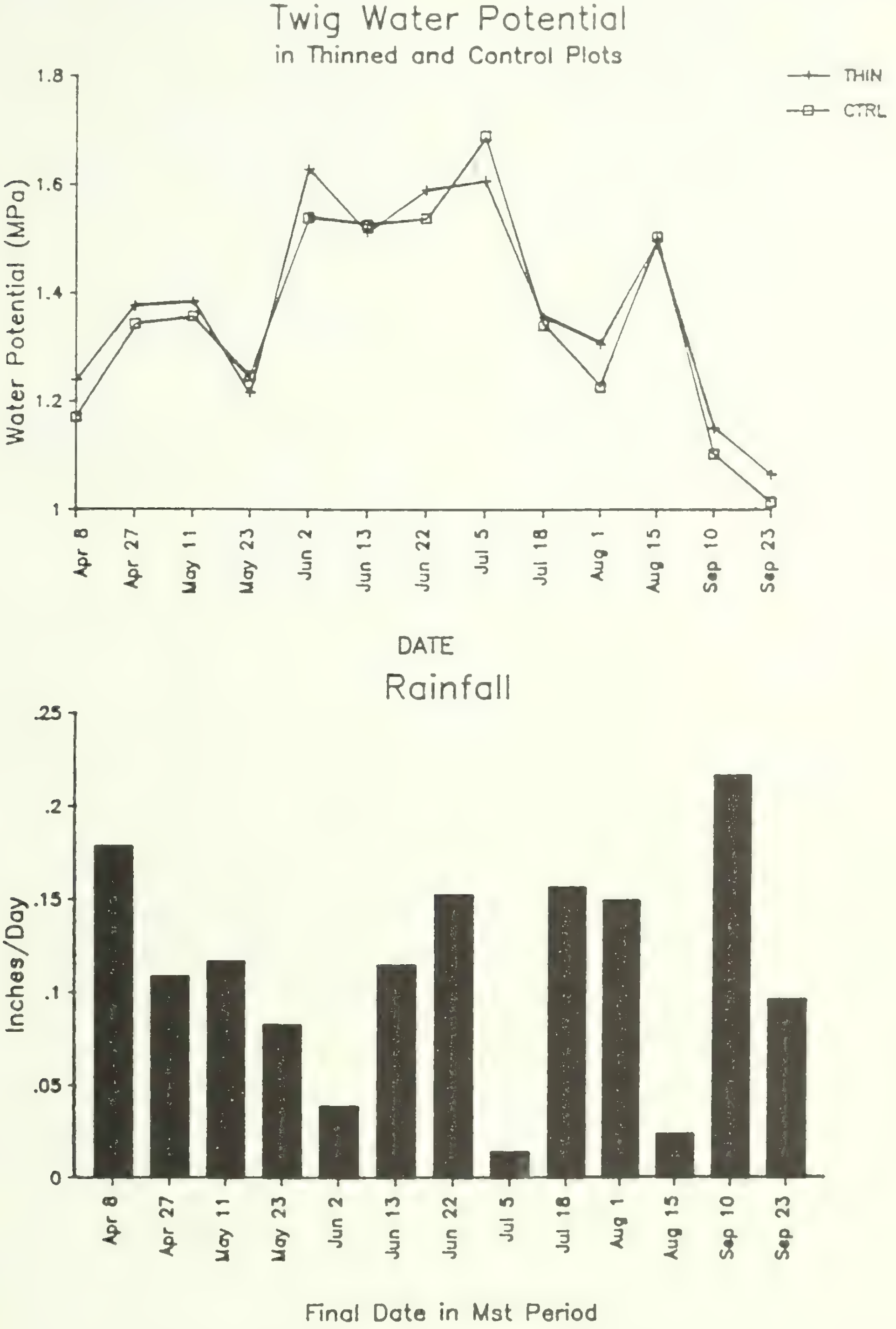

Figure 4.--Rainfall and midday water potentials through the summer of 1988. Rainfall is expressed as the number of inches that fell during a measurement period divided by the number of days in the measurement period.

1964, McClurkin 1961, Della-Bianca and Dils 1960, and Zahner and Whitmore 1960) have found that growth differences following thinning were dependent upon differences in water availability. The rainfall pattern on the Virginia Piedmont during the summer of 1988 was rather uncharacteristic and may be responsible for the lack of physiological differences between trees in the thinned and control plots. Rainfall was plentiful throughout the summer (fig 4). Thus the late summer drought which is typical in the southeastern United States, and during which water stress is most likely to occur, never materialized. Since water was not a limiting factor, it is not surprising that needle photosynthesis was unchanged as a result of thinning.

As mentioned earlier, thinning shock was not observed. Trees in thinned stands did not exhibit reduced growth rates. In addition, there was no evidence of solarization--bleaching of the needles due to photo-oxidation of chlorophyll--in the suddenly exposed lower crown needles in thinned plots. In fact, the lower crown needles in both the thinned and control plots had higher photosynthetic rates than did needles from the upper crown and when released they can immediately begin to contribute photosynthate to the tree.

This higher photosynthetic rate of shade-grown needles is contrary to the generally accepted relationship between sun and shade needles. Sun needles are considered to have higher photosynthetic rates than shade needles when photosynthesis is measured at high light levels (Kramer and Kozlowski 1979), as it was in this study. However, results similar to ours have been reported for some conifer species. Bourdeau and Laverick (1958) found that needles from red pine seedlings grown in the shade had higher photosynthetic rates than needles from sun-grown seedlings at a wide variety of light intensities including full sunlight. Ronco (1970) reported the same findings for lodgepole pine (Pinus contorta Dougl. ex Lond.) and Engelmann spruce (Picea engelmanni Parry ex Engelm.) seedlings. Bourdeau and Laverick attributed the difference in photosynthetic rates to differences in water potentials and chlorophyll concentrations for the two sets of seedlings. Water potentials were generally lower in lower crown twigs than in upper crown twigs in our study (fig 5) as well.

In his study of mature loblolly pines, Higginbotham (1974) observed that needles in the top third of the canopy had a lower capacity for carbon dioxide uptake than needles in the middle and lower thirds at all light intensities from

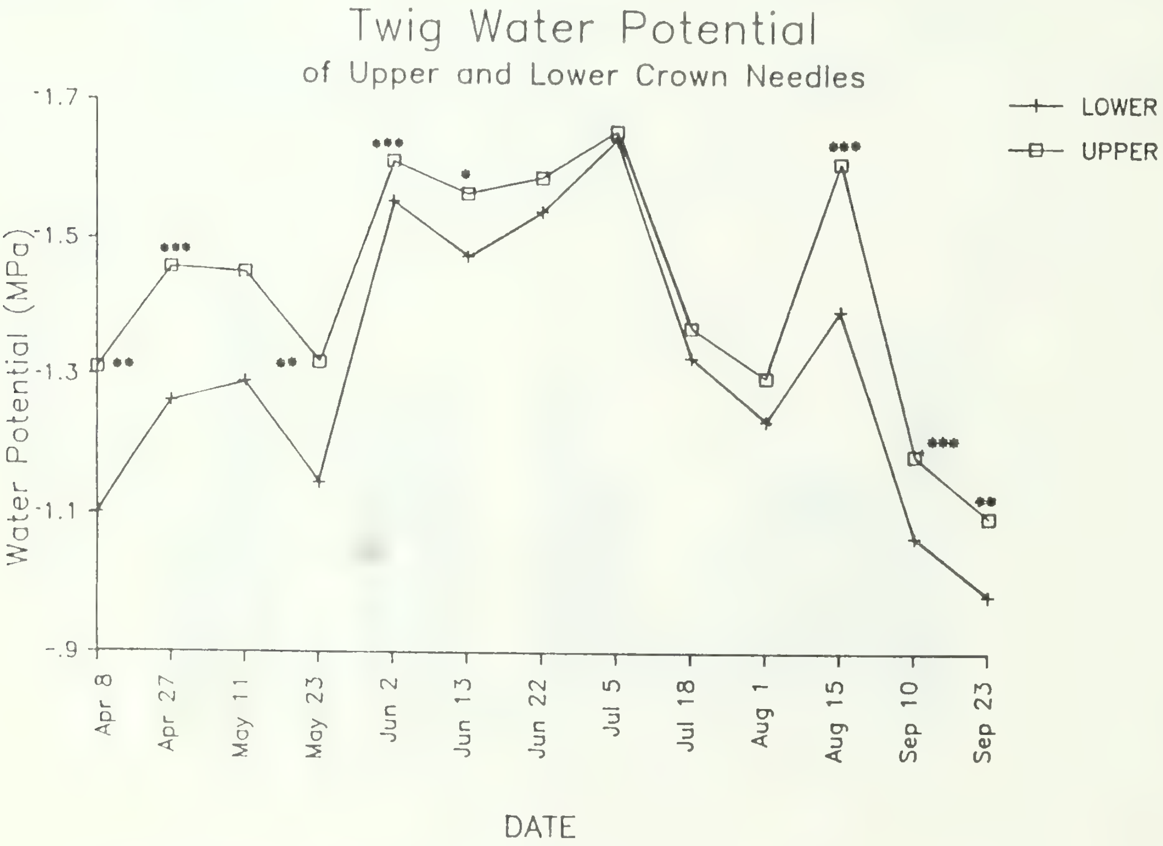

Figure 5.--Midday water potentials of twigs in the upper and lower thirds of loblolly pine crowns through the summer of 1988. * indicates a significant difference between crown positions at alpha = 0.10; ** indicates significance at alpha = 0.05; *** indicates significance at alpha = 0.01.

one-tenth of full sun to full sun. He found no difference between the chlorophyll concentrations in needles of different crown positions, contrary to the observations of Bourdeau and Laverick.

The results of all four of these studies with conifers indicate that shade-grown needles are capable of higher photosynthetic rates than sun-grown needles when exposed to full sunlight. A similar immediate response to sunlight was found in this study with needles from the lower canopy of control plots. Because shade-grown needles in the lower crown are able to respond so rapidly, lower branches in thinned stands can immediately begin to contribute significantly to the growth of the tree.

CONCLUSIONS

From the results that were observed during the first year following thinning, the following conclusions were drawn:

1) Thinning of young loblolly pines increases crown size by increasing crown diameter growth and delaying death of lower crown branches.
2) Lower crown, shade-grown needles are able to respond immediately to increased light levels.
3) Whole-tree photosynthetic rates are increased after thinning because of the increase in crown size and the increase in available light.
4) Individual needle photosynthetic rates are not affected by thinning when water potential does not differ between thinned and control plots.

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THE RELATIONSHIP OF LEAF AREA TO SAPWOOD AREA IN LOBLOLLY PINE AS AFFECTED BY SITE, STAND BASAL AREA, AND SAPWOOD PERMEABILITY[1]

Victor B. Shelburne, Roy L. Hedden and Robert M. Allen[2]

Abstract.--Stem cross-sectional sapwood area (SA) was linearly related to leaf area (LA) with SA at the base of live crown a better predictor of LA than SA at breast height. Prediction equations for LA had different slopes between basal area classes but not between site classes. The effect of including permeability in the LA prediction equations was minimal. Mean ratios of LA to SA at all heights were significantly different between basal area classes but not site classes.

INTRODUCTION

The ability to predict leaf area from sapwood area at various heights in the tree is a valuable tool in determining net assimilation or growth efficiency in individual trees or whole stands. Numerous studies have been done on the linear relationship between the basal area of conducting tissue (sapwood) with foliage weight or leaf area in various species (Blanche et al. 1985, Grier and Waring 1974, Rogers and Hinckley 1979, Shinozaki et al. 1964a, 1964b, Waring et al. 1981, Waring et al. 1982, Whitehead 1978). However, the effect of site quality and stand density on the relationship between sapwood basal area and leaf area in loblolly pine (Pinus taeda L.) has not as yet been fully explored. Furthermore, additional information is necessary on the permeability of the sapwood.

The effect of site on the leaf area:sapwood area relationship has been investigated in Douglas-fir (Pseudotsuga menziesii Mirb.). Brix and Mitchell (1983) found that a combination of nitrogen fertilizer treatments and thinnings significantly increased the slope of the leaf area-sapwood area regression equation in stands of this species. However, Grier et al. (1984) did not achieve statistically significant differences between the regression slopes for fertilized and unfertilized stands of Douglas-fir. They attributed the lack of regression slope differences to a lack of sufficient time for the post-fertilized foliage to fully develop, which was estimated to be 4-7 years by Brix and Mitchell (1983).

Effect of stand density on the relationship between leaf area/sapwood area has been studied in lodgepole pine (Pinus contorta Dougl.) by Pearson et al. (1984) and Keane and Weetman (1986). Leaf area per unit of sapwood ranged from .20 to .57 m^2/cm^2 in stands of different densities, ages and sites in the Pearson study. The highest amount of leaf area per unit sapwood area was observed in the low density, old growth stand, whereas the lowest ratios were calculated for high density stands (Pearson et al. 1984).

The relationship between leaf area and sapwood area in loblolly pine has received attention only recently. Blanche et al. (1985) developed a leaf area/sapwood area ratio in order to rate loblolly pine vigor. Forty-five trees ranging in age from 17 to 80 years were selected from fourteen natural stands in east central Mississippi. Thirty-one trees were sampled in May (minimum foliage) and 14 more were sampled in late August (maximum foliage). Other than this difference in collection period, no site or stocking data were noted and therefore the regression equations were based only on the time of collection. In this study, the influence of these factors on loblolly pine was more closely examined.

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OBJECTIVES

1. Relate loblolly pine foliage area (m^2) to sapwood area (cm^2) at breast height and determine whether this relationship is affected by site and stand basal area.

2. Determine the relationship of sapwood permeability and earlywood area on the leaf area-sapwood area ratio.

METHODS

Thirty-six loblolly pine trees from a matrix of two levels of stocking and two site classes were sampled. Four stands which represented extremes of stocking and site index were located on the Clemson Experimental Forest. Stand basal area was determined using a 10 basal area factor prism from three points randomly selected in each stand before the sample trees were chosen. Stand site index (index age 50) was determined by obtaining age and height data from the three dominant trees used in the study. Site index equations (Farrar 1973) were used to determine the actual site index values which agreed well with previously collected data on these stands.

Nine trees (three trees from each of three dominance classes--dominant, intermediate, and suppressed) were randomly selected from each of the four stands. The nine trees from each stand were considered to be a plot and the four plots were designated as follows: Plot 1 (LSHD)-low site (SI = 70), high stand density (BA = 140 sq. ft./ac.); Plot 2 (LSLD)-low site (SI = 70), low stand density (BA = 90); Plot 3 (HSLD)-high site (SI = 100), low stand density (BA = 90); Plot 4 (HSHD)-high site (SI = 110), high stand density (BA = 160). The low density stands (plots 2 and 3) had been thinned; however, there was no actual record as to the year of these thinnings, but based on the remnant stumps in the stands, both thinnings had occurred no less than five years previously. Age of the four stands ranged from 29-31 years. All trees were cut during the dormant season between January 15 and March 25, 1985. Two disks with an approximate thickness of 2.5 cm each were removed at breast height (1.37 m), base of live crown, and halfway in between for each tree. These disks were frozen at -17.8°C in plastic bags for later determination of sapwood area.

One tree from each dominance class (dominant, intermediate, and suppressed) was cut from each of the four original stands in the summer of 1987. Disks were removed from these 12 trees at the same three positions (breast height, base of live crown, and midway in between) as the original trees. The disks were returned to the laboratory and cut radially from the pith outwards in four directions at 90 degree angles. Permeability determinations were made within a week of cutting in all cases. Disks were stored in plastic bags at 6°C until they were prepared. Preparation of the specimens for permeability measurement followed the general procedures outlined by Booker and Kininmonth (1978) for Monterey pine (Pinus radiata). Permeability of the disks was determined in darcys. As many specimens with a width that could accommodate the 21 mm outside diameter O-ring which was part of the permeability test apparatus were cut successively in each radial direction.

The 108 disks (36 trees x 3 heights) which had been previously sanded for percent sapwood area determination were cut across the cross-section so that the slice (approximately 2.5 cm wide) would contain tree rings across a representative diameter from bark to bark. Heartwood was determined using a standard staining technique. These samples were then measured using a digital ring measuring device. Measurements were made of the earlywood and latewood widths for each ring.

RESULTS

Using the leaf areas for the 36 original trees in the study, various independent variables were selected for use as predictors. Most variables varied with bole height, and a separate prediction equation could be derived for each stem position (lower, middle, and upper) in the tree. However, some variables such as dbh and height to live crown had only one value per tree.

Table 1 shows the various R^2 values for some of the independent variables tested in this study to predict leaf area. Since diameter at breast height (dbh) and height to live crown (htlc) have only one value per tree (no change due to stem position), the values are reported in the cell for lower stem position (breast height).

Height to live crown (table 1) was the poorest predictor of leaf area. However, this variable is not related to any area measurement in this study but the determination was made because of the hypothesis that height might have some value in predicting leaf area. The other variables, all of which were related to some sapwood area measurement, were all good predictors. Diameter at breast height (cm) had an R^2 value of .85 overall. Although the value was only .80 for plot 1 (LSHD), it was .97, .94, and .95 for plots 2 (LSLD), 3 (HSLD), and 4 (HSHD) respectively. It should be noted that the the pooled data for all the plots show that the R^2 values increase with increasing height in the tree; however, within the individual plots, this trend sometimes reversed itself. This is somewhat contrary to the general hypothesis that sapwood area at the base of live crown is a better predictor of leaf area than sapwood area at breast height and is probably related to the site and stand specific quality of these equations.

Table 1.--Coefficients of determination (R^2) for various independent variables used to predict leaf area

Plot	Stem Position	Height to Live Crown	Diameter Breast Height	Sapwood Area	Sapwood Area 10 yrs	Sapwood Area 5 yrs	Earlywood Total	Earlywood 10 yrs	Earlywood 5 yrs
All Plots	L[1]	.22	.85	.88	.84	.83	.83	.79	.81
	M	--	--	.91	.85	.84	.88	.78	.79
	U	--	--	.92	.84	.82	.90	.80	.77
1 (LSHD)	L	.09	.80	.73	.86	.87	.57	.72	.69
	M	--	--	.83	.84	.89	.74	.72	.79
	U	--	--	.82	.84	.83	.72	.72	.69
2 (LSLD)	L	.18	.97	.96	.97	.97	.96	.95	.95
	M	--	--	.99	.97	.98	.98	.95	.97
	U	--	--	.94	.95	.95	.97	.92	.95
3 (HSLD)	L	.28	.94	.96	.89	.80	.93	.80	.77
	M	--	--	.96	.86	.79	.93	.76	.72
	U	--	--	.91	.85	.82	.89	.78	.73
4 (HSHD)	L	.33	.95	.92	.94	.93	.84	.90	.93
	M	--	--	.91	.92	.95	.90	.89	.93
	U	--	--	.93	.97	.97	.93	.97	.98

[1] L = lower; M = middle; U = upper.

Because permeability decreases with distance from the bark, an in-depth look at various quantities of sapwood area as leaf area predictors was attempted. Specifically, sapwood areas of the most recent five-and ten-year intervals were used because of their generally high permeability value. Likewise, earlywood area (total, five-year and ten-year) alone was also used because of the generally high permeability values associated with it. No overall improvement was noted using these new variables. In fact, relative to total sapwood area, the R^2 values were generally lower although not by much in most cases. Also, the total measurements of sapwood area and earlywood area were generally better than the five- and ten-year area values. This is probably because these total values account for more variation in the data. Furthermore, the total sapwood values are probably more highly correlated with tree size which is likewise more correlated with total leaf area than five- or ten-year areas.

One obvious problem with fine tuning this relationship is that R^2 values are already very high for both sapwood areas and dbh (>.90 in most cases) and attempts to improve these values are confounded by the random variability and error associated with the relationship.

Using the permeability relationships data obtained in this study, attempts were made to combine the sapwood area information and the predicted permeabilty for the various heights in the tree (Shelburne 1988). This was done by multiplying the area of sapwood (total, 10-year, and 5-year) by the average predicted permeability for the given area to obtain average conductance values. The conductance values generated by these equations were used to predict leaf area and the coefficients of determination are presented in table 2. The results did not generally improve the relationships previously discussed.

Table 2.--Coefficients of determination (R^2) for conductance values used to predict leaf area

Plot	Stem Position	R^2 Conductance values Total	10 year	5 year
All Plots	L[1]	.76	.75	.74
	M	.81	.85	.84
	U	.82	.79	.75
1 (LSHD)	L	.69	.75	.80
	M	.80	.82	.87
	U	.81	.82	.83
2 (LSLD)	L	.45	.68	.74
	M	.57	.80	.85
	U	.67	.82	.91
3 (HSLD)	L	.97	.92	.88
	M	.94	.88	.83
	U	.91	.88	.85
4 (HSHD)	L	.86	.93	.91
	M	.82	.91	.92
	U	.96	.97	.98

[1] L = lower; M = middle; U = upper.

The prediction equations for leaf area using total sapwood area as the independent variable are presented in table 3. These three equations used the sapwood area data for all 36 trees in the study and are grouped by stem position (upper, middle, and lower) such that each equation was derived using 36 points. The plots of these equations are presented on the same graph in figure 1. Obviously, the upper position has the steepest slope since the amount of sapwood area is less at the base of live crown. The lower position has the least slope and the middle position is in between. A test of heterogeneity of slopes indicated that they were all significantly different from one another ($p < .01$) as might be expected.

Table 3.--Leaf area (LA) prediction equations using total sapwood area (SA) as the dependent variable

Plot(s)	Stem Position	N	Equation	R^2
All	L[1]	36	LA=.28SA - 6.30	.88
All	M	36	LA=.35SA - 1.40	.91
All	U	36	LA=.54SA + 2.72	.92
1 (LSHD)	L	9	LA=.26SA - 10.4	.73
1	M	9	LA=.37SA - 8.1	.83
1	U	9	LA=.52SA - .5	.82
2 (LSLD)	L	9	LA=.285SA + .79	.96
2	M	9	LA=.45SA - 5.6	.99
2	U	9	LA=.62SA + 1.13	.94
3 (HSLD)	L	9	LA=.33SA - 5.3	.96
3	M	9	LA=.37SA + 2.9	.96
3	U	9	LA=.52SA + 12.0	.91
4 (HSHD)	L	9	LA=.24SA - 11.9	.92
4	M	9	LA=.31SA - 7.15	.91
4	U	9	LA=.54SA - 5.6	.93
Blanche et al. (1985)			LA=.27SA + 3.71	.87
Johnson et al. (1985)			LA=.271SA	.96

[1] L = lower; M = middle; U = upper.

Also included in table 3 are the equations developed by Blanche et al. (1985) for 31 dominant or codominant trees felled in the spring and the equation for 60 loblolly pine seedlings developed by Johnson et al. (1985). Sapwood area was measured at breast height (lower position) in this study and the Mississippi study but was measured at the base of the seedling (root collar) with the seedling study. Despite the small difference in the intercepts, the slopes for the three studies are not significantly different (.28 in this study versus .27 in the Mississippi study and .271 in the seedling study). Considering possible variations in data collection methods, differing genetic stock, and the fact that this study used the three major dominance classes unlike the Mississippi study, the similarity of the final equations leads to the hypothesis that this relationship may be species specific (genetic) when data are collected from trees representing a range of site and stand conditions.

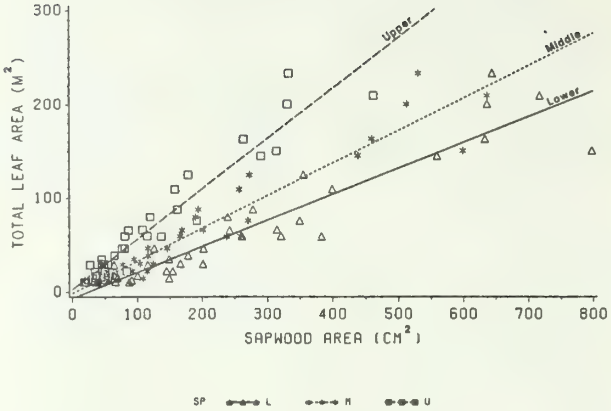

Figure 1.--Leaf area prediction from sapwood area by stem position (SP) using data from all four plots.

The equations presented in table 3 are plotted in figure 2 which shows the overlays of the four plots by stem position. Covariance analysis was used to test whether there were significant differences among the y-intercepts of the four plot equations at the same stem position. None of them were significant. The slopes of each of the four equations were also compared within each stem position using a test for the heterogeneity of slopes. Within the upper position, none of the four equations had a significantly different slope from any other. In the middle position, there was a significant difference in slope between the two extremes of site index and stand basal area (plot 2-LSLD vs plot 4-HSHD) with the lower basal area plot having the higher slope (more leaf area per unit area sapwood). In the lower position, there was a significant slope difference between plot 4 (HSHD) and plot 2 (LSLD). All other comparisons indicated no significant differences in slope.

A review of figure 2 shows that, while not necessarily significant in all cases, differences between equations were due to differences in stand basal area. In all three stem positions, the two low basal area plots (2 and 3) were consistently higher in slope than the two high basal area plots (1 and 4) regardless of site. When the data were combined by similar stand basal area, e.g. high basal area plots were combined, two equations were generated for each stem position instead of four. A comparison of the slopes of these two equations within each stem position showed that there was a significant difference ($p < .01$) at the lower position, a significant difference ($p < .05$) at the middle position, but no significant difference at the upper position.

This lack of difference at the upper position is due to the lack of difference in slope between any of the original four equations at the upper position. This observation coupled with the higher R^2 of the upper position prediction may be due to the generally held hypothesis that sapwood at the base of live crown is a better predictor of leaf area than any other height (Blanche et al. 1985). Because more of this area of wood is conducting water (due to less heartwood and the generally higher permeability determined earlier), this position may better reflect the moisture requirements of the tree that are manifested in the leaf area. To further test the effect of site on the relationship, the data for similar sites (plots 1 and 2 vs plots 3 and 4) were combined and differences in slope were tested. In these cases, no differences in slope were found at any of the three positions which lent further proof that differences in the leaf area-sapwood area relationship are more strongly affected by stand basal area than site factors.

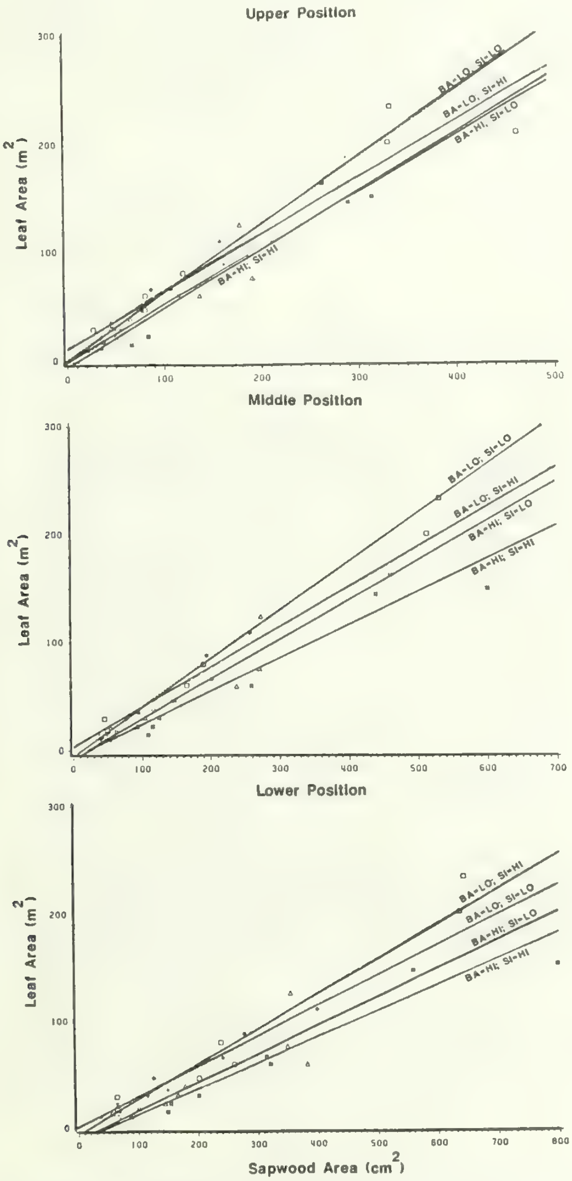

Figure 2.--Comparison of leaf area prediction equations by plot (site index and stand density) and stem position.

Another approach to the leaf area-sapwood area relationship is to test for differences between the ratio of leaf area (m^2), dominance class, and sapwood area (cm^2) on the basis of plot and stem position. Using regression, we attempted to predict the relationship between one variable (sapwood area) and another (leaf area). Simple ratio analysis shows this relationship without any prediction. For this reason, there will be differences between the slopes of prediction equations and the ratios.

An analysis of variance to determine the effects of plot, dominance class, and stem position on the ratio indicated that plot, stem position ($p <.01$), and dominance class were significant ($p <.05$). By arranging the data in various ways, it was possible to discern these differences in greater detail. Contrasts between all plots indicated that stand basal area was significant ($p <.01$). The low basal area plots had an average leaf area/sapwood area ratio of .44 as opposed to the ratio of .32 on the high basal area plots (table 4). These same contrasts indicated no difference due to site. Earlier analyses indicated that sapwood area and leaf area were significantly affected by site but not stand basal area. Because the ratio of the two is not affected by site, there must not be a concommitant change in one variable with respect to the other; otherwise, the effect of site would have remained. When contrasts were made between individual plots, the same trends were noted. Plots 2 and 3 (both low basal area) had no significant difference between them. Likewise, plots 1 and 4 (both high basal area) were not significantly different; however, the average ratios of each of these plots were significantly different ($p <.01$) from the other two plots of unlike basal area.

Table 4.--Comparison of leaf area/sapwood area ratio by stand density, site index, and plot

Plot(s)	Leaf area/sapwood area ratio
2 and 3 (low density)	.44 a[1]
1 and 4 (high density)	.32 b
1 and 2 (low site index)	.38 a
3 and 4 (high site index)	.38 a
1 (LSHD)	.33 a
2 (LSLD)	.43 b
3 (HSLD)	.45 b
4 (HSHD)	.31 a

[1] Means followed by same letter (within group) are not significantly different at the .05 level (Ryan-Einot-Gabriel-Welsch F-test).

CONCLUSIONS

The effects of stand basal area and site quality on the relationship between leaf area and sapwood area in loblolly pine were quantified through the use of statistical comparisons of regression slopes and ratios which link these two variables. Regression equations which predict leaf area from sapwood area and leaf area:sapwood area ratios differ on the basis of stand basal area and not site quality. Therefore, the anticipated linear proportionality between leaf area and sapwood area was not achieved because of major differences in stocking between stands. As noted, the ratio and slope values of this relationship for those stands in low basal area stands are consistently and significantly greater than those values for high basal area stands regardless of site quality. This result supports the conclusions of other investigators who have studied the effects of site and stand density on the leaf area/sapwood area relationship of other tree species (Brix and Mitchell 1983, Marchand 1984, Pearson et al. 1984, Keane and Weetman 1986).

The permeability relationships developed in this study did not improve the ability to predict leaf area even though the quantificatio of these relationships by site, stand basal area, dominance class, and tree height should have allowed a better prediction to occur if permeability were that important to the relationship. Either the permeability relationships developed in this study are too indeterminant to be of value in predicting leaf area or the the effect of these values on the leaf area-sapwood area relationship is not strong.

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GROWTH OF NORTHERN RED OAK SEEDLINGS PLANTED IN A CENTRAL MISSOURI CLEARCUT AND SHELTERWOOD[1]

Debra D. Crunkilton, Harold E. Garrett, and Stephen G. Pallardy[2]

Abstract.- Northern red oak (Quercus rubra L.) seedlings, both containerized one-year-old stock inoculated with Pisolithus tinctorius and two-year-old bare-rooted uninoculated seedlings, were planted on a favorable oak site under a 60% shelterwood and in a clearcut in central Missouri. Half of the seedlings were clipped at approximately 20 cm above the root collar. During the first year after overstory cutting, seedlings in the shelterwood planting had significantly less diameter and height growth, and lower photosynthetic rates and leaf water potentials (ψ_1) than did seedlings in the clearcut. Containerized seedlings had significantly greater diameter growth than did the bare-rooted seedlings following outplanting and significantly higher predawn ψ_1 in the shelterwood. However, photosynthetic rates did not vary. Unclipped two-year-seedlings in the shelterwood had significantly less survival than all other seedlings.

INTRODUCTION

Inadequate natural oak regeneration and slow initial growth of bare-root nursery stock (Johnson 1979, Merritt 1979, Ruehle 1984) has led to increased interest in developing faster growing planting stock (Garrett et al. 1979, Dixon et al. 1981, Dixon et al. 1983, Parker et al. 1986). Manipulation of the overstory of planting sites (Johnson 1984, Johnson et al. 1986) has also been employed in attempts to increase planting success. Seedlings grown in containers with mycorrhizae or auxins have greater numbers of lateral roots, greater comparative absorptive surface area, improved water and nutrient relations (Tinus 1978, Dixon et al. 1983, Pope 1984, Baser et al. 1987), and consequently, higher rates of growth and survival. Johnson (1984) demonstrated that two-year-old bare-root seedlings survived better than did one-year-old bare-root seedlings. He also found that clipping the shoot of 2-0 bare-root seedlings (thus increasing the root to shoot ratio) enhanced subsequent shoot growth rate in northern red oak (Quercus rubra L.). Johnson (1988) further demonstrated that undercutting seedlings in the nursery increased their lateral and tap root dry weight and surface area and subsequent survival in the field.

Although species of the Erythrobalanus (red oak) subgenus of Quercus grow best in full sunlight (McGee 1968), competing vegetation can outgrow newly planted seedlings of these species. Sander (1979) found that oaks planted in a shelterwood which were allowed to become established before removing the overstory had greater survival and growth than did oaks planted in a clearcut. Planting in a 60 percent stocked shelterwood cut, combined with weed control to decrease competition and release after three years can substantially increase the chances of successful oak establishment (Johnson 1984).

Many oak sites are characterized by droughty soils and intense competition for soil moisture. Photosynthesis in woody plants declines during drought (Hinckley et al. 1978, Kramer and Kozlowski 1979). Plants vary in their capacity to maintain a favorable internal water balance during periods of drought (Bordeau 1954). Improved water relations may increase seedling photosynthesis and growth potential. Measurements of photosynthesis and water relations can therefore allow better evaluation of treatment effects on seedling physiology and growth.

The objectives of this study were to establish and compare the effects of several treatments on certain physiological processes and plant growth and survival through the first summer after outplanting. Nonmycorrhizal, two-year-old seedlings and mycorrhizal, one-year-old, containerized seedlings, either clipped or unclipped were compared. These seedlings were planted in a clearcut and a 60 percent stocked shelterwood.

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METHODS

Seedling Culture

Bare-root stock was grown in conventional nursery beds during 1985 and 1986 at the George O. White State Forest Nursery in Licking, Missouri. Roots were undercut at about 20 cm in April of 1986. The seedlings were lifted March 31, 1987 and bundled in sphagnum moss surrounded by kraft baling paper. This planting stock was stored at 5°C until planted on April 11, 1987. At the time of planting, roots were trimmed to 20 cm and half of the shoots were clipped at 20 cm above the root collar.

Containerized stock was grown in Spencer-LeMaire Super 45 (750 cm^3) root trainers in a shadehouse. The growth medium consisted of a 1:1:1 (v/v/v) soil:peat:vermiculite mixture. Medium in each cavity contained 2 gm IBA-polyacrylic starch (750 ppm IBA) prepared as described by Baser et al. (1987), except that the solution was freeze-dried for three days instead of heat-dried for 50 days. Pisolithus tinctorius, a mycorrhizal forming fungus, was prepared as described by Marx and Bryan (1975) and 20 ml of inoculum was added to the upper 500 ml of growth medium in each cavity.

In May, 1986, pregerminated acorns were planted in alternate cavities of the containers. Seedlings were watered three times per week and fertilized weekly with modified Hoagland's solution (Hoagland, 1950). The containers were buried in sawdust to overwinter.

Study Sites and Planting Design

A northeast-facing, high quality oak stand (site index 26 m for northern red oak) totaling about 2 ha in size located on the Mark Twain National Forest in central Missouri was prepared for planting. This stand was divided into two contiguous sites. Half of the forest on each site was inventoried and thinned to a 60 percent level of stocking to form a shelterwood as described by Gingrich (1967). All sugar maple trees (Acer saccharum Marsh.) were mechanically removed from the sites to decrease competition. Stumps were sprayed with Tordon RTU (Dow Chemical Co., Midland, MI) to inhibit sprouting and a 20-m buffer strip was formed around each planting area.

Prior to planting, diameter at 4 cm above the root collar and height from the root collar to the shoot tip were measured on all seedlings. At the time of planting, all containerized seedlings were mycorrhizal, with approximately 85 percent of the lateral roots infected. Only 20 percent of the bare-root seedlings were mycorrhizal, with about 21 percent of the lateral roots infected. All seedlings were hand-planted with tile spades in a randomized complete block design April 11 and 12, 1987. There were eight treatments consisting of nonmycorrhizal, two-year-old bare-root seedlings and mycorrhizal, one-year-old, containerized seedlings, clipped and unclipped and planted in a clearcut and shelterwood. There were four replications and eight trees per treatment per replication on each site for a total of 512 trees. The spacing was 3 m between seedlings of different treatments and 1.2 m between trees within a treatment. Half of the containerized seedlings had the shoot clipped following planting.

Experimental Measurements

Predawn leaf water potential (ψ_1) was measured weekly from June through September. A leaf from three randomly selected seedlings within each treatment was excised prior to sunrise. Seedlings sampled were enclosed in a plastic bag the previous evening to inhibit nocturnal transpiration and reduce the influence of dew. Excised leaf samples were placed in plastic bags with moist paper towels to minimize transpirational water loss prior to measurement (Parker and Pallardy 1985). Predawn ψ_1 was estimated in the field with a Scholander pressure chamber as described by Ritchie and Hinckley (1975).

Diurnal measurements of photosynthetic photon flux density (PPFD) and photosynthesis were conducted between 1000 and 1400 hours true solar time. On four selected days from June to August, estimates of PPFD were made with a quantum sensor mounted on a LI-COR Steady State Porometer (Model 1600 LI-COR Inc., Lincoln, NE). Measurements were conducted on four seedlings from two randomly chosen replications of each treatment (a total of 64 seedlings). Gross photosynthesis was measured by $^{14}CO_2$ incorporation into leaf tissue using the method of Shimshi (1963) and Naylor and Teare (1975) as modified by Dean (1981). A leaf was exposed to a $^{14}CO_2$ - $^{12}CO_2$ mixture (300-350 ppm) with a known specific radioactivity. An exposed disc was removed from each leaf sampled and placed in 1 ml of 50% nitric acid contained in a scintillation vial. This procedure killed the tissue and prevented respiratory CO_2 loss (Wolf and Carson 1973). In the laboratory the tissue was digested in a water bath and then 15 ml of scintillation cocktail was added to the vial. The sample was counted in a scintillation counter and, after correction for counting efficiency, the data were converted to gross photosynthesis. In August and September, measurements of diurnal photosythesis and PPFD were made with a portable photosynthesis system (Model 6200, LI-COR Inc., Lincoln, NE).

In October, 1987 survival, diameter at 4 cm above the ground and height from the ground to the shoot tip were measured on all seedlings. Leaf area of 16 randomly selected seedlings per treatment was measured with a portable area meter (Model 3000, Li-Cor Inc., Lincoln, NE). In March 1988, two seedlings per treatment were excavated on each site and total root length, percent mycorrhizal colonization and root and shoot dry weight were assessed on these seedlings.

RESULTS

Slightly over 30 cm of rain fell from June 3 to September 19, which approximates the average for central Missouri during this time period. Precipitation was distributed in 36 rainstorms with a noticeable dry period occurring in late July.

Excavation revealed that seedlings of all treatments were mycorrhizal by the spring following planting. The bare-root seedlings were colonized with two distinctly different types of unidentified mycorrhizae. The containerized seedlings supported those two types as well as the Pisolithus tinctorius with which they were planted.

Diameter and height growth were greater in the clearcut than in the shelterwood (table 1). Predawn ψ_1, PPFD and photosynthetic rates were higher in the clearcut than in the shelterwood (table 2). Leaf area and root length were also greater in the clearcut than in the shelterwood (table 3).

Table 1.-- Diameter (Dm) and height (Ht) growth and survival (Surv) between March and October 1987 for one-year-old containerized (1) and two-year-old bare-root (2), northern red oak seedlings in a clearcut (C) and a shelterwood (S).

	GROWTH		
Treatment	Dm (mm)	Ht (cm)	Surv (%)
1C	3.6^{a*}	25^{a}	89^{a}
2C	-3.5^{c}	10^{b}	84^{ab}
1S	0.7^{b}	7^{b}	91^{a}
2S	-3.8^{c}	4^{b}	80^{b}

*Note: Significant differences between treatments are based on LSD tests ($p \leq 0.05$); means within a column superscripted with the same letter are not significantly different.

One-year-old containerized seedlings had greater root to shoot dry weight ratios, longer root systems (table 3) and greater survival (table 1) than did two-year-old bare-root seedlings. One-year-old containerized seedlings in the clearcut had the largest diameter and height growth (table 1), root length, root to shoot dry weight ratio (table 3) and photosynthetic rates (table 2) of all seedlings. Within the shelterwood, containerized seedlings had higher predawn ψ_1 (table 2), root to shoot ratio (table 3), and survival (table 1) than did bare-root seedlings.

Clipping had no significant effect on one-year-old containerized seedlings after one year in the field except for increasing the root to shoot ratio in the clearcut (4.7 clipped versus 2.0 unclipped). However, with two-year-old bare-root seedlings, clipping increased shoot growth (from 6 to 15 cm in the clearcut and from 1 to 9 cm in the shelterwood) and increased survival in the shelterwood (from 66 to 94%) while decreasing survival in the clearcut (from 91 to 77%). Two-year-old bare-root unclipped seedlings in the shelterwood had the poorest survival (66%) of all the seedlings.

Table 2.-- Mean predawn leaf water potential (ψ_1), photosynthetic photon flux density (PPFD), and photosynthetic rate (Ps) for the period June - September 1987 for one-year-old containerized (1) and two-year-old bare-root (2) northern red oak seedlings in a clearcut (C) and a shelterwood (S).

Treatment	predawn ψ_1 (MPa)	PPFD (μmol/m^2/sec)	Ps (μmol/m^2/sec)
1C	-0.13^{a*}	1490^{a}	7.3^{a}
2C	-0.14^{a}	1480^{a}	6.1^{b}
1S	-0.42^{b}	213^{b}	2.6^{c}
2S	-0.76^{c}	282^{b}	2.2^{c}

*Note: Significant differences between treatments are based on LSD tests ($p \leq 0.05$); means within a column superscripted with the same letter are not significantly different.

Table 3.-- Leaf area (LA), root length (RL) and root to shoot dry weight ratio (R:S) one growing season following outplanting for one-year-old containerized (1) and two-year-old bare-root (2) northern red oak seedlings in a clearcut (C) and a shelterwood (S).

Treatment	LA (cm^2)	RL (cm)	R:S (ratio)
1C	621^{a*}	2043^{a}	3.4^{a}
2C	569^{a}	954^{b}	2.1^{bc}
1S	187^{b}	1011^{b}	2.9^{ab}
2S	233^{b}	458^{b}	1.4^{c}

*Note: Significant differences between treatments are based on LSD tests ($p \leq 0.05$); means within a column superscripted with the same letter are not significantly different.

DISCUSSION

The presence of an overstory had a significant influence on seedling growth during the first summer following planting. During the growing season, seedlings in the clearcut had greater diameter and height growth than did seedlings in the shelterwood. This is similar to the findings of Johnson (1984) and can be explained by several factors. Photosynthetic rates in the clearcut were higher than in the shelterwood, partly because of higher light levels. Seedlings in the clearcut received greater PPFD due to less shading by the young herbaceous vegetation than from the residual trees in the shelterwood. Moreover, predawn ψ_1 was higher in the clearcut, apparently because there was less competition for water from the recently established herbaceous vegetation than from residual shelterwood trees. This reduced competition in the clearcut resulted in less seedling water stress and sustained stomatal opening (Kramer and Kozlowski 1979) and mesophyll capacity for CO_2 fixation (Kaiser 1987). Greater photosynthetic rates would enable more carbon acquisition, a result that would in part explain the greater root growth found in the clearcut. Increased root length of seedlings planted here further enhanced water relations by increasing the absorbing surface area. Greater photosynthetic rates can also help explain greater leaf area development in the clearcut which subsequently increased net seedling photosynthate production and growth as a simple application of the compound interest law. Containerized seedlings in the clearcut had higher photosynthetic rates than bare-root seedlings. This likely resulted at least partly from their greater root length and root to shoot ratio which would allow greater water uptake.

The decreasing diameter of two-year-old seedlings can be explained in part by the fact that diameters were measured at somewhat different heights in the two samples taken. While diameter was measured at 4 cm above the root collar prior to outplanting, at the end of the growing season the seedlings were measured at 4 cm above the ground level. While seedlings were planted with the root collar near ground level some settling occurred. Therefore the second diameter measurement was taken higher on the seedling. Since the bare-root seedlings had significant taper, diameter appeared to decrease after one growing season. Furthermore, the shoots of some bare-root seedlings died back and resprouted, yielding diameters substantially smaller than recorded at the time of outplanting. One-year-old containerized seedlings, which were significantly smaller, had much less taper and did show an increase in diameter.

Root to shoot dry weight ratios and root length were greater in the containerized seedlings than in the bare-root seedlings after one year in the field. This was also found to be true before planting. Johnson (1979) found that containerized oak seedlings have more primary laterals from which they can initiate rapid root growth than do bare-rooted stock. Containers concentrate root growth in the planted volume. In contrast, bare-root seedlings are only planted with a portion of their root system intact. Furthermore, the roots of bare-root seedlings are not protected by soil during lifting, storage, transport and planting as are containerized seedlings; hence, roots are subject to greater desiccation injury and shock. Survival of containerized seedlings was likely greater than bare-root seedlings because of the reduced shock and the presence of a more vigorous root system at the time of planting.

Clipping the shoots of seedlings at planting significantly increased the root to shoot ratio after one year only for containerized seedlings planted in the clearcut. This may explain the greater shoot growth of these seedlings compared to the unclipped containerized stock in the clearcut. The root to shoot ratio of other seedlings was only nominally increased by clipping. Two-year-old unclipped bare-root seedlings in the shelterwood had the lowest root to shoot ratio, a result that may in part explain their significantly lower survival and height growth. The presence of greater water stress and lower photosynthetic rates in the shelterwood along with lower root to shoot ratios of unclipped seedlings likely increased mortality and decreased shoot growth.

More research is needed to follow the physiology and growth of the seedlings through time. Sander (1979) and Johnson et al. (1986) found that oak seedlings planted under a shelterwood had greater survival and growth than those planted in a clearcut when, three years after underplanting, the shelterwood was removed. In our study, competitors in the clearcut during the second growing season began to overtop many of the planted trees. This will decrease PPFD and likely increase competition for available water. Moreover, it may result in a reversal of the first-year findings. Nevertheless, during the first season after planting, a clearcut appears to offer the better environment for oak seedling establishment.

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Seedling Production

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USE OF SEEDLING SIZE AS A COVARIATE FOR ROOT GROWTH POTENTIAL STUDIES[1]

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Abstract. -- Measurements of root growth potential are often dependent on seedling morphology (i.e. size of the root system). When this occurs, covariate analysis can provide a means of removing the potential confounding effect of differences in morphology. Covariance analysis can be useful in reducing experimental error. Additional information from available data can also be achieved by use of covariance analysis. Several examples are presented to illustrate the potential effect of this type of analysis on the interpretation of treatment effects. Due to rapid fluctuations in RGP over time, covariance analysis (based on seedling size) may be less useful when RGP is sampled over time than when the measurements are from one point in time.

INTRODUCTION

Root growth potential (RGP) is a measure of a seedling's ability to initiate and elongate roots when placed into an environment favorable for root growth (Ritchie 1985). In the South, researchers are currently interested in measuring this attribute since outplanting survival can sometimes be correlated with RGP (Feret and others 1986; Hallgren and Tauer 1987; Larsen and others 1986). Since 1980, there have been over 35 papers that involve measuring the RGP of southern pine seedlings.

When outlining the basic procedures for measuring RGP, Ritchie (1985) stated that "since seedling size can also affect RGP, it may be desirable either to (1) select seedlings of relatively uniform size for the test (which will bias the results) or to (2) analyze the results using morphological properties as covariates." However, this type of analysis is seldom used for RGP studies. There have only been a few studies where RGP values have been adjusted for differences due to seedling morphology (Larsen and Boyer 1986; Williams et al. 1988).

Conclusions regarding the results of any experiment can depend on the type of analysis used. In some cases, commonly used statistics can result in incorrect conclusions regarding the data (Warren 1986). The objective of this paper was to compare the results of evaluating RGP data with either the traditional analysis of variance (ANOVA) or with covariate analysis. The authors have attempted to explain how the interpretation of the data can vary with the type of analysis used.

MATERIALS AND METHODS

Data reported here are from 3 container studies (studies 1, 2, and 3) and 9 bare-root studies (table 1). Except for four studies (1, 10, 11 and 12), treatments were laid out in the nursery in a randomized complete block design. Two studies (2 and 3) involved split-plots.

RGP was determined in each study by using either a hydroponic method (Ritchie 1985) or by potting the seedlings in sand (Larsen and Boyer 1986) and placing the containers on a heating bed. All studies were conducted in a greenhouse in order to provide high light intensity for production of photosynthate. Photoperiod was extended to either 15 or 16 hr. Root temperature was maintained at either 25 or 27°C.

Prior to placing seedlings in the test, all white root tips were removed and heights and diameters were recorded. After four weeks (three weeks for the bud type study), RGP was determined by measuring the number of new roots that were greater than 0.5 or 1.0 cm in length. After removal of the new roots, the weight of the remaining (original) root system was determined.

For each study, data were analyzed using both analysis of variance and covariate analysis. In all but two studies, seedling diameter was used as the covariate. Total seedling weight was used as the covariate in study 1 and original root weight was used in study 10.

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Table 1.--Information regarding the RGP studies

Study	Seed source	RGP test	Lifting date	Treatments
1. Bud type	half-sib	21-day water	Nov., Dec, Jan.	3 bud types; ± storage
2. Fertilization	half-sib	30-day water	Nov., Jan.	3 levels of Diammonium phosphate (DAP)
3. Fertilization	half-sib	30-day water	Dec., Jan.	DAP vs. ammonium nitrate vs. control
4. Seed spacing	orchard mix	28-day sand	Dec.	1.9, 2.8, 4, 5, 6 cm spacing
5. Seed spacing	orchard mix	28-day sand	Jan.	1, 2, 3, 4, 5, 6 cm spacing
6. Seed spacing	Livingston P.	28-day sand	Dec.	1, 2, 4, 6 cm spacing
7. Irrigation	orchard mix	30-day water	Dec.	irrigation vs. no fall irrigation
8. Irrigation	orchard mix	30-day water	Jan.	irrigation vs. no fall irrigation
9. Nursery	half-sib	28-day sand	Dec.	7 nurseries
10. Nursery	Livingston P.	28-day sand	Dec.	20 nurseries
11. Lift date	half-sib	28-day water	Sept.-March	3 sowing dates; 14 lift dates
12. Lift date	half-sib	28-day water	Sept.-March	15 lift dates; with and without buds

RESULTS AND DISCUSSION

In ten of the studies, seedling morphology accounted for a significant amount of variation in RGP (the covariate in most cases was significant at the 0.0001 level of probability; table 2). In general, treatments that increased seedling size (i.e. additional fertilization, additional irrigation, lowering seedbed density) also increased RGP. This agrees with previous research that demonstrates that larger loblolly pine seedlings tend have higher RGP than smaller seedlings (Barden 1987; Brissette and Roberts 1984; Carlson 1986).

The use of covariance analysis can often aid the experimenter in understanding the principles underlying the results of an investigation. This type of analysis can help to explain if an increase in RGP is confounded with an increase in seedling size. The following are some examples of how the interpretation of RGP data might be improved by using covariance analysis.

Study 1

Without covariance analysis, the conclusions from this study would be that storage, bud type and seedling age (lifting date) affected RGP (table 2). However, the covariance analysis suggests that bud type and seedling age are confounded with seedling size. The affect of these variables on RGP could simply be explained by older seedlings being larger and seedling with buds being larger than seedlings without well formed buds.

Study 2

Without covariance analysis, the conclusions would be that increased nitrogen fertilization increased RGP. However, the covariance analysis suggests that rate of fertilization may have an effect on RGP which is over and above that of increasing seedling size.

Study 3

Regardless of method of analysis, the conclusion is that source of nitrogen had no effect on RGP. However, the covariance analysis also indicates that regardless of the lack of treatment effect, there still exists a positive relationship between seedling size and RGP.

Studies 4 and 5

Without covariance analysis, the conclusion is that RGP increases with lower seedbed densities. However, with the covariance analysis, the conclusion is that the increase in RGP can be accounted for simply by the effect of seedbed density on seedling size.

Table 2.--Comparison between ANOVA and Analysis of Covariance for various RGP studies

	ANOVA				Analysis of covariance			
Study	Source	df	F value	P > F	Source	df	F value	P > F
1. Bud type					covariate	1	134.3	0.0001
	bud type	1	51.7	0.0001	bud type	1	1.0	0.3850
	lift date	2	528.4	0.0001	lift date	2	2.1	0.1332
	storage	2	1227.2	0.0001	storage	2	11.2	0.0014
	error	54			error	53		
2. Fertilization					covariate	1	31.0	0.0001
	block	3	0.4	0.7413	block	3	9.0	0.0123
	treatment	2	65.1	0.0001	treatment	2	32.3	0.0006
	error A	6			error A	6		
3. Fertilization					covariate	1	24.5	0.0001
	block	3	0.7	0.5849	block	3	0.9	0.5043
	treatment	2	3.6	0.0933	treatment	2	3.0	0.1259
	error A	6			error A	6		
4. Seed spacing					covariate	1	35.6	0.0001
	block	4	0.7	0.5872	block	4	2.1	0.1157
	treatment	4	5.1	0.0074	treatment	4	1.1	0.3754
	error	16			error	15		
5. Seed spacing					covariate	1	78.1	0.0001
	block	4	4.2	0.0128	block	4	4.2	0.0097
	treatment	5	11.5	0.0001	treatment	5	0.3	0.8868
	error	20			error	19		
6. Seed spacing					covariate	1	26.1	0.0001
	block	4	2.8	0.0769	block	4	1.9	0.1471
	treatment	3	3.2	0.0616	treatment	3	6.0	0.0073
	error	12			error	11		
7. Irrigation					covariate	1	82.6	0.0008
	block	2	3.3	0.2308	block	2	.4	0.5700
	treatment	1	427.6	0.0111	treatment	1	0.0	0.8585
	error	2			error	1		
8. Irrigation					covariate	1	10.6	0.0056
	block	7	2.5	0.1249	block	2	1.5	0.2395
	treatment	1	1.9	0.2105	treatment	1	1.8	0.1960
	error	7			error	6		
9. Nursery					covariate	1	33.5	0.0001
	nursery	6	5.3	0.0001	nursery	6	5.5	0.0001
	error	189			error	188		
10. Nursery					covariate	1	192.5	0.0001
	nursery	19	10.3	0.0001	nursery	19	8.0	0.0001
	error	369			error	368		
11. Lift date					covariate	1	0.3	0.5707
	block	3	1.8	0.1487	block	3	1.9	0.1343
	lift date	13	25.4	0.0001	lift date	13	24.1	0.0001
	sowdate	2	42.4	0.0001	sowdate	2	41.1	0.0001
	error	123			error	122		
12. Lift date					covariate	1	0.2	0.6520
	sample	14	3.2	0.0009	sample	14	3.2	0.0008
	bud	1	14.2	0.0004	bud	1	13.9	0.0004
	error	60			error	59		

Study 6

For this density study, covariance analysis, greatly increased the precision of the test (table 3). In addition, for this test, there may exist an effect of seedbed density on RGP which is independent of seedling size.

Study 7

With ANOVA, the conclusion is that RGP was increased by fall irrigation. However, the covariance analysis indicates that this effect may simply be due to the treatment causing an increase in seedling size.

Study 8

Regardless of method of analysis, the conclusion is that RGP was not increased by fall irrigation. However, the covariance analysis also indicates that regardless of the lack of treatment effect, there still exists a positive relationship between seedling size and RGP.

Studies 9 and 10

With ANOVA, the conclusion is that RGP varies by nursery. With covariance analysis, the conclusion is that differences among nurseries exists even after taking into account differences in seedling size.

Study 11 and 12

For these two studies, the type of analysis made no difference to the conclusions because the covariate did not account for a significant proportion of the variation. This can be explained by the fact that RGP can change rapidly (either up or down) during a 2 week period while seedling diameter normally increases only slightly during the same period. In otherwords, the relationship between seedling size and RGP was masked by the rapid fluctuation in RGP over time.

In all of the studies, covariance analysis provided more information than the regular ANOVA. In 8 cases, the use of covariate analysis helped to interpret the nature of the treatment effects. In 4 of the studies, the effect of various treatments on RGP could be completely explained by the changes in seedling morphology.

In 10 studies, the error mean square was reduced by 13 to 65% (table 3). For these cases, the precision of the test was increased by the use of covariate analysis. Covariance analysis did not improve the precision of studies that involved sampling RGP over a long period of time (September to March).

The improvement in precision will depend on which morphological trait is used as the covariate. For example, use of seedling height as a covariate will not be as consistently reliable as root-collar diameter, root volume, root weight, or weight of lateral roots.

Table 3.--Error mean square reduction by use of covariance analysis

Study	ANOVA	Covarince	% decrease
	-- error mean square --		
Study 1	255	160	37%
Study 2	194	129	33%
Study 3	646	473	27%
Study 4	315	177	44%
Study 5	528	349	34%
Study 6	1314	480	63%
Study 7	35	12	65%
Study 8	108	89	18%
Study 9	2289	1984	13%
Study 10	308	244	21%
Study 11	88	91	-
Study 12	34	32	5%

In some cases, the use of multiple covariance analysis may result in further improvement in precision (Woollons and Whyte 1988). Multiple covariance has been used to adjust RGP values for differences in morphology among seedling samples (Larsen and Boyer 1986). Since RGP is dependent on current photosynthesis, it might be possible to improve the precision of tests by including foliar nitrogen content along with morphological covariates such as diameter or lateral root weight.

CONCLUSIONS

Covariance analysis of RGP tests can be useful in increasing the precision of the test. In addition, this type of analysis can be helpful in determining if the treatment response can be simply related to a change in seedling size. The trait used as the covariate should be related to the size of the root system rather than the height of the shoot. Covarinace analysis based on morphology will be useful when (1) RGP is measured in one point in time; and (2) RGP is affected by some nursery treatment. This type of analysis may be less effective when the RGP data are from a date of lifting study.

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COMPARING THE EFFECTS OF EQUAL VERSUS INCREASING APPLICATION RATES OF NITROGEN ON THE QUALITY OF SHORTLEAF PINE SEEDLINGS[1/]

John C. Brissette, Allan E. Tiarks, and William C. Carlson[2/]

Abstract.--During nursery growth, seedlings from half-sib families were fertilized with a total of 90 kg N/ha, either in equal increments or at a geometrically increasing rate. The N was supplied as ammonium sulfate $[(NH_4)_2SO_4]$. Shoot morphological characteristics were significantly affected by family. There were significant interactions between family and application method for both root morphology and root growth potential (RGP). When compared to equal applications, the increasing rate method produced better balanced seedlings with greater RGP for some families, but not all.

INTRODUCTION

The addition of nitrogen (N) fertilizers as top dressings (broadcast applications during seedling development) is common practice in bare-root nursery culture (Armson and Sadreika 1979, May 1984, van den Driessche 1984). Top dressings with N are usually in several light, equal applications through the first half of the growing season. Recently, Timmer and Armstrong (1987) produced red pine (Pinus resinosa Ait.) container seedlings that were larger and had smaller shoot-to-root ratios when N was supplied at an exponentially increasing rather than a constant rate. They concluded that the increasing rate of application better met the needs of the seedlings as they grew and that the constant rate provided too much N early in seedling development, and consequently may have inhibited root development.

Shortleaf pine (P. echinata Mill.) seedlings from an Arkansas nursery had the largest root collar diameters and greatest root volumes when supplied with a relatively high seasonal total of ammonium sulfate $[(NH_4)_2SO_4]$ (170 kg N/ha) (Brissette and Carlson 1987a). However, the seedlings were tallest and had the greatest root wth potential (RGP) when a more moderate otal was applied (110 kg N/ha). The results from that study, plus the findings of Timmer and Armstrong (1987) led to the design of another experiment dealing with the effects of ammonium sulfate on shortleaf pine. The results of one part of that study, the effects of applying the same total amount of N in either five equal increments of 18 kg N/ha or in four geometrically increasing rates starting at 6 kg N/ha, are discussed in this paper. Half-sib family seedlots from a seed orchard were used in the study. The objectives were to determine if the two application strategies produced seedlings with different shoot and root characteristics, if RGP differed, and if application method and family had an interactive effect on morphology and RGP.

MATERIALS AND METHODS

Seeds from half-sib shortleaf pine families used in this study were collected from four clones in the Ouachita-Ozark National Forest seed orchard near Mount Ida, Arkansas. The clones are from the Ouachita National Forest (115 and 138) and the Ozark National Forest (322 and 342) in Arkansas. These families were chosen based on full-sib progeny tests where the selected clones were the female parents. When the families were selected, only survival data were available. Overall survival was compared in several field tests; survival of progeny from 115 and 322 was above average and survival from 138 and 342 was below average.

After stratification for 60 days, the seeds were sown in mid-April 1987 at Weyerhaeuser Company's Magnolia Forest Regeneration Center in

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southwest Arkansas. The experiment was laid out on four adjacent nursery beds; each bed was considered a block in the experimental design. The beds were divided into two sizes of experimental units, 24- by 1.3-m plots for families and 3- by 1.3-m fertilizer plots within each family plot. Two sizes of plots were used because this arrangement provided the maximum information about both family and fertilizer treatments with a minimum requirement for seeds and nursery bed space. The families were assigned at random to the large plots within each block, and the fertilizer treatments were assigned at random to the small plots within each family plot, resulting in a split-plot, randomized block design. A Weyerhaeuser Company designed precision sower was used to sow 8 double rows across the nursery beds at a target density of 220 seedlings per m^2.

Fertilization with prilled ammonium sulfate began 6 weeks after sowing and continued at 2-week intervals. Ammonium sulfate is the form of N fertilization used operationally at the Magnolia nursery because it has proven to be as effective as other forms of N fertilizer for growing quality pine seedlings. Besides maintaining relatively low soil pH, any other impact of sulfate in the fertilizer on seedling growth is considered minimal under the conditions at the nursery. The two treatments discussed here received a total of 90 kg N/ha at the increasing rates of 6, 12, 24, and 48 kg N/ha for the geometrically increasing application strategy and five applications of 18 kg N/ha for the constant application method. Application was with a Gandy model 604 drop-type fertilizer spreader pulled behind a tractor. All other cultural practices, including undercutting and lateral root pruning, were based on the best judgments of the nursery manager and applied uniformly to the entire study. Top pruning is not practiced at the Magnolia nursery.

Seedbed density was measured on each small plot just before the first fertilization. Germination of family 115 was poorer than expected, resulting in an average seedbed density of just 88 percent of the 220 per m^2 target. The densities of the other three families averaged between 97 and 101 percent of the target, and plot differences among these families were not significant. Seedbed density has a tremendous effect on shortleaf pine seedling morphology and field performance (Chapman 1948, Brissette and Carlson 1987a, b). Therefore, data from family 115 were not included in the anlayses and are not presented.

In December 1987, two eight-tree samples, one seedling from each drill row, were carefully hand lifted from near the center of each fertilized plot. Seedlings from one sample were measured to characterize morphology. The other sample was used for RGP testing.

The shoot characteristics measured were: total height, root collar diameter, whether the terminal bud had brown scales, and the total ovendry weight of the eight-seedling sample. For analysis, the proportion of seedlings from each plot with buds was transformed to the arc sine of the square root of that proportion. This transformation ensures that proportional data have a reasonably normal distribution with homogeneous variance (Freese 1974). Root measurments taken were: volume (by displacement in water) and root area index (RAI) for each seedling and total ovendry weight of the sample. The RAI is an estimate of the total root system projected surface area (Morrison and Armson 1968). It was measured using a video camera coupled to a Delta-T Device area meter (Decagon Devices Ltd.). The measurements of three different images of each root system were averaged to obtain the RAI for a seedling (Rietveld and Tinus, in press). For characteristics measured on individual seedlings, the means of the eight-tree samples were used in the analysis.

The RGP tests were conducted in a growth chamber set at a constant 20 °C with a 16-h photoperiod. The floor of the chamber was kept flooded to maintain the relative humidity above 50 percent. Seedlings were potted in coarse sand, two per 1-L milk carton. The containers were watered regularly to keep the sand at near field capacity, but no fertilizer was used. After 28 days, the seedlings were carefully washed from the sand. The RGP was measured on each seedling as the difference between RAI before and after the test (Rietveld and Tinus, in press). Means of the eight-seedling samples were used in the analysis. Because several correlated variables were measured, multivariate analysis of variance (MANOVA) was used to determine treatment effects on seedling morphology. Shoots and roots were analyzed separately.

Multivariate analysis describes the simultaneous relationships among variables by examining the convariances or correlations that reflect the extent of the relationship among those variables (Dillon and Goldstein 1984). Rather than comparing factor and level means as in univariate ANOVA, MANOVA simultaneously analyzes the dependent variables as linear combinations. One linear combination is possible for each dependent variable in the model, and for each combination an eigenvalue can be extracted from the matrix of sums of squares and cross products of those variables. The eigenvalue that represents the greatest separation between levels of a factor is extracted first, and the magnitude of each subsequent eigenvalue is smaller. Significance in MANOVA is tested by comparing functions of the eigenvalues of the matrices of the main and interaction effects with the eigenvalues of the appropriate error matrix. Thus, the MANOVA tests are analogous to, and have an exact or approximate relationship with, the familar F-test. Although there are others, one commonly used test in MANOVA is the Wilk's Lambda (Dillon and Goldstein 1984), and that is what we have used.

The MANOVA's were followed up with individual ANOVA's of each measured characteristic. Also, ANOVA was used to examine treatment effects on RGP. A significance level of 0.05 was used.

RESULTS

Correlations among the morphological characteristics measured for the three families retained in the study are shown in table 1. Seedling height was best correlated with shoot ovendry weight and moderately correlated with root collar diameter, but was not correlated with any of the other attributes. Root collar diameter, the one seedling attribute most often used to describe size, was well correlated with both shoot and root dry weight and with root volume. The proportion of seedlings with over-wintering terminal buds was not correlated with any other characteristic. Among the root characteristics, root volume and root ovendry weight had the highest correlation, probably because they are both primarily functions of taproot mass. The RAI was well correlated with root volume and moderately correlated with root ovendry weight. We think RAI is a better measure of root system ramification than either root volume or ovendry weight because it depends more on the number of lateral roots and their branching patterns than on tap root size.

When the effects of family and method of N application were compared using MANOVA, differences in both shoots and roots were significant. For shoot morphology, the differences were due to family, not to the method of N application or the interaction between family and N (table 2). The interaction between family and N did have a significant effect on root morphology (table 2). The MANOVA's were followed up with ANOVA's of each of the measured characteristics (table 3). The differences in seedling height were significant among the families ($p = 0.03$), but none of the other individual attributes had significant differences. Family 342 was shortest (200 mm), and 138 (221 mm) and 322 (232 mm) were similar. Although not statistically significant, all of the families had fewer seedlings with over-wintering buds when N was applied at increasing rates.

On an ovendry weight basis, shoot-root ratio was not affected by the interaction between family and N application method. It differed among families ($p = 0.03$): 342, the shortest family, also had a smaller ratio (2.98) than 138 or 322, which were the same (3.40). However, when compared in field tests, the full-sib progeny of clones 138 and 322 have had better overall survival than the progeny of 342. The shoot-root ratio was also somewhat smaller ($p = 0.09$) for the increasing N application method (3.18) than for the constant rate method (3.34).

Table 1.--Correlation coefficients (r) and levels of significance (p) among several shoot and root morphological characteristics for seedlings from three half-sib shortleaf pine families

		RCD[1]	Buds	SODW	RV	RAI	RODW
Ht	(r)	0.575	0.057	0.728	0.350	0.091	0.438
	(p)	(0.003)	(0.791)	(0.001)	(0.094)	(0.673)	(0.032)
RCD	(r)		0.221	0.825	0.841	0.528	0.899
	(p)		(0.300)	(0.001)	(0.001)	(0.008)	(0.001)
Buds	(r)			0.274	0.114	0.018	0.042
	(p)			(0.196)	(0.597)	(0.933)	(0.844)
SODW	(r)				0.705	0.392	0.794
	(p)				(0.001)	(0.058)	(0.001)
RV	(r)					0.830	0.901
	(p)					(0.001)	(0.001)
RAI	(r)						0.641
	(p)						(0.001)

[1] RCD=root collar diameter, Buds=arcsin (square root [proportion with buds]), SODW=shoot ovendry weight, RV=root volume, RAI=root area index (see text), RODW=root ovendry weight.

Table 2.--Results of MANOVA's for shortleaf pine seedling shoot and root morphology[1]

Source	Shoot Eigenvalues	Shoot Wilk's Lambda	Root Eigenvalues	Root Wilk's lambda
Family	25.2246 0.4552 0.0000	F=3.883 p=0.058	1.1370 0.4345 0.0000	F=1.001 p=0.485
N application method	1.4142 0.0000	F=2.121 p=0.196	1.5158 0.0000	F=3.537 p=0.076
Family X N	0.8153 0.0677 0.0000	F=0.588 p=0.770	4.5314 0.0642 0.0000	F=3.328 p=0.030.

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[1] Family values were obtained from data taken from the whole plot; N application data, either equal or increasing rates, were from the subplots.

Table 3.--The effect on shortleaf pine seedling characteristics of applying 90 kg of N per ha in biweekly equal increments versus geometrically increasing increments at 6, 12, 24 and 48 kg/ha

Family	N application method	Characteristic[1] Height	 RCD	 Buds	 RV	 RAI	 SODW	 RODW
		------mm-------		-percent-	--cm^3--	---cm^2---	-------gram---------	
138	Equal	223±11[2]	4.3±0.2	87.5±5.1	3.3±0.3	24.5±2.8	3.80±0.25	1.10±0.09
	Increasing	220±6	4.3±0.1	75.0±8.8	3.2±0.1	25.0±1.3	3.74±0.13	1.12±0.04
322	Equal	231±11	4.2±0.2	71.9±10.7	2.7±0.3	20.4±2.2	3.56±0.41	1.02±0.11
	Increasing	234±17	4.4±0.2	59.4±12.9	3.2±0.3	21.4±1.7	3.95±0.42	1.21±0.13
342	Equal	188±11	4.3±0.1	71.9±13.9	3.4±0.1	25.9±1.6	3.52±0.17	1.17±0.05
	Increasing	212±12	4.6±0.2	65.6±13.9	3.5±0.3	24.9±2.2	3.70±0.39	1.26±0.09

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[1] RCD=root collar diameter, Buds=presence of resting bud, RV=root volume, RAI=root area index (see text), SODW=shoot ovendry weight, RODW=root ovendry weight.

[2] Mean and standard error of four replications with eight samples per replication.

For RGP, the interaction between family and N application method was significant ($p = 0.04$). Family 342 had much greater RGP when N was applied at the geometrically increasing rate compared to the equal rate (fig. 1). Family 138 also had greater RGP for the increasing rate, but the RGP of family 322 did not differ much between the two application methods. In this study, RGP was not correlated to any of the morphological characteristics measured.

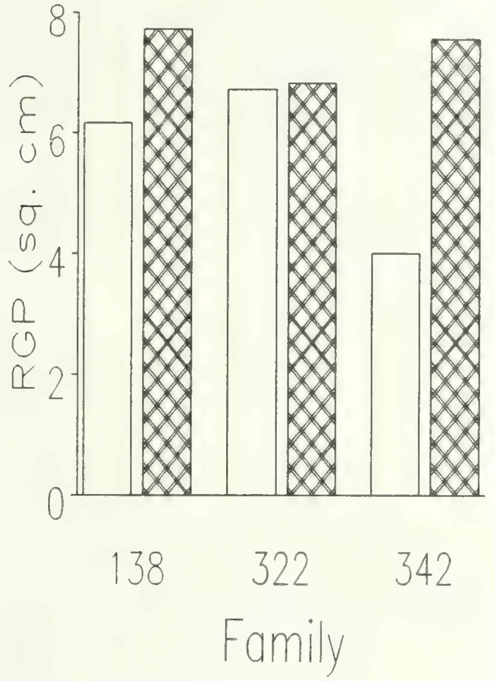

Figure 1.--Effects of half-sib family and whether N was applied in equal increments (solid bars) or at a geometrically increasing rate (cross hatched bars) on the RGP (projected surface area) of bare-root shortleaf pine seedlings.

DISCUSSION

The results of this study suggest that N fertilizer applied at an increasing rate, rather than the conventional equal or constant rate, may produce morphologically better balanced seedlings with a greater RGP. The method of application had a greater effect on seedling roots than on their shoots. However, the effects on morphology were subtle and were only detected when several characteristics were compared simultaneously using a multivariate approach. Also, not all the families studied responded the same to the two application methods. Family 138 showed little morphological effects due to the method of N application, but it did have greater RGP under the increasing rate regime. The morphology of both families 322 and 342 differed with the two fertilizer treatments, but only 342 had a difference in RGP. Although the difference between the N treatment effect on the proportion of seedlings with overwintering buds was not significant in this study, poorer budset may indicate delayed dormancy and reduced cold hardiness. However, Wakeley (1954) was unable to relate the presence of a terminal bud to survival after outplanting for any of the southern pines.

Applying N at an increasing rate is a potentially promising alternative to the conventional method. The effect on field performance will be an important indication of the value of this type of application.

DEDICATION

We dedicate this paper to the memory of R. P. Plyler. As the long-time manager of the nursery at the Magnolia Forest Regeneration Center in Arkansas, R. P. contributed his knowledge and experience to the planning and conduct of this and other studies designed by the authors. His enthusiasm for nursery research and interest in applying the results were extremely beneficial and he will be missed.

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FREQUENCY DISTRIBUTION OF FIRST-ORDER LATERAL ROOTS IN FOREST TREE SEEDLINGS: SILVICULTURAL IMPLICATIONS[1]

Paul P. Kormanik[2]

Abstract.--Five years after outplanting, sweetgum (*Liquidambar styraciflua* L.) nursery seedlings with $\geq$7 first-order lateral roots (FOLR) had 30% higher survival and twice the stem volume of seedlings with $\leq$3 FOLR at planting time. In a study of progeny of 12 mother trees, loblolly pine (*Pinus taeda* L.) seedlings with $\leq$3 FOLR had poorer stem and root characteristics than seedlings with $\geq$4 FOLR. The poorer seedlings comprise over one-third of the seedling population examined. Data relating number of FOLR at outplanting to field performance of loblolly pine will be available in 2 to 3 years.[3]

INTRODUCTION

In naturally regenerated stands, foresters can rely on stem and crown characteristics to judge a tree's competitive potential before they manipulate stand structure. This approach is reliable because stand structure normally is not modified until crowns close and dominance is expressed. By then, the effects of variation in competitive potential are apparent. Root development of individuals is difficult to study so it has seldom been observed. Indeed, generalities in tree root structure and function as reported before 1900 (Busgen and Munch 1929) have not been modified much in recent years (Zimmerman and Brown 1971). Our ignorance of root development may be harmless in natural stands, but it could be causing costly mistakes in plantations.

There is no doubt that it is easier to judge a tree by its top than by its roots. Tops are visible and top growth is easily manipulated with developing nursery technology. One of the primary goals of nursery technology has been to standardize size quality so that lifting and shipping require a minimum of hand labor. It has been suggested that with good nursery practices only diseased or mechanically damaged seedlings have to be discarded (Wakeley 1954; USDA Forest Service 1985).

Great emphasis was placed on producing seedlings of uniform size after Wakeley (1954) showed that performance after outplanting varied directly with root-collar diameter and height of nursery stock. Nursery management prescriptions were directed towards nutritional practices that enabled even the slowest growing seedlings to meet Wakeley's minimum standards for a grade 2 seedling. Tops of larger, more vigorous seedlings were clipped several times during the growing season to maintain uniform seedling height in nursery beds (USDA Forest Service 1985). Effective insecticides and fungicides for control of nursery insects and diseases made it possible to produce uniform stock that could be sold by weight instead of by counting individual seedlings. This practice was widely accepted because it reduced hand labor. But what the affects were on seedling performance after outplanting we do not know. Early recognition of a seedling's quality is still considered by the Southern Industrial Forestry Research Council (1984) to be a major problem in artificial regeneration and increased fiber production.

The constituents of seedling quality will not be discussed in detail here. Many references are already available and these have been summarized and paraphrased many times (Duryea and Landis 1984; Duryea 1985; USDA Forest Service 1985). Characteristically, however, quality of planting stock has been quantified primarily from height, root collar diameter, and top/root ratio. All of these measurements are readily altered by nursery practices.

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[3] This study was supported by U.S. Department of Energy Interagency Agreement No. DE-AI09-76SR-00870 and Georgia Forestry Commission Collection Agreement No. 29-303.

Have we been correct in ignoring variability in seedling size and assuming that seedlings are equal if their tops have reached some predetermined physical size? The results obtained during the past 20 years makes me think not. My own research during the past 10 years, initially with sweetgum (*Liquidambar styraciflua* L.) seedlings (Kormanik 1986) and later with seven other tree species, led me to speculate that "regardless of the phenotypic characteristics of a mother tree, associated progeny will exhibit a range in seedling development related to distribution of permanent first-order lateral roots and that seedlings with fewer lateral roots will be less competitive in a forest environment" (Kormanik and Muse 1986). Note, there is no reference to seedling size. The predominant evidence supports the conclusion that, in a uniform portion of any nursery bed, the largest seedlings will generally be the most competitive. The larger seedlings will also have the best first-order lateral root development. However, what is "large" in one part of a nursery bed might be considered "small" in another part of the same nursery or of the same nursery bed. The eventual equal field performance of seedlings of different stem sizes finally reduced the utility of Wakeley's (1954) grading system and has been a major deterrent in developing a more reliable one based primarily on stem characteristic alone.

Work at the U.S. Department of Agriculture, Forest Service, Institute for Mycorrhizal Research and Development in Athens, Georgia, indicates that first-order lateral root (FOLR) numbers may be useful in identifying a seedling's competitive potential and may provide a basis for developing a biologically simple and sound grading system for bare-root nursery stock. It must be emphasized, however, that no single factor will ever delineate quality in a seedling. Nursery practices do affect seedling quality. When included with other measures, however, lateral root numbers may be useful in predicting the competitive potential of artifically regenerated seedlings. Root characteristics may be less important for initial survival than for competition after the canopy closes (Loehle and Namkoong 1987).

Seedling Production

Detailed nursery procedures for producing seedlings for FOLR studies at the Mycorrhizal Institute have been reported several times (Kormanik 1986; Kormanik and others 1982) and will not be repeated here. What is important, however, is that there probably is not a single prescription for growing even one species under all nursery conditions.

A protocol for developing such a prescription will have to be developed. This baseline, among other factors, will take into account what fertility is needed to produce a seedling with specific desirable qualities. In general, nurseries may be applying more fertilizer than is required to produce high quality seedlings. Seedlings of the lowest competitive potential may be dictating fertilizer regimes for the entire seedling population.

The idea of counting FOLR came from research with sweetgum (Kormanik 1986). Several years of research results indicated that at similar seedbed densities, nursery fertility practices significantly alter seedling stem size, but usually have only a minimal influence on number of strong FOLR. We maintain seedbed densities of 6/ft^2 for hardwoods and 25/ft^2 for loblolly pine (*Pinus taeda* L.). Under our experimental nursery protocols, we normall count only first-order lateral roots that are ≥1 mm at the proximal end (at the taproot) and have a mature suberized periderm. These standards are used in assessing the roots of all species so far examined. It is realized, however, that the 1 mm diameter minimum may not be appropriate for all species, i.e., it may be too small for walnut and oaks and may not be small enough for some southern pines. By maintaining a specific FOLR diameter, however, a constant framework for comparative purposes has been developed. Regardless of species, we use only half-sib progeny. Our purpose is to obtain genetic information on heritability of FOLR in various hardwood and conifer species.

RESULTS

Only results with sweetgum and loblolly pine will be reported here. For sweetgum we have significant nursery and field data that indicate performance through 5 years after outplanting. For loblolly pine, we only have nursery data at this time, but we are engaged in major cooperative efforts with the Georgia Forestry Commission and will have results of outplanting trials in a few years.

Sweetgum.--The seedlings in our initial lateral root studies were placed in three FOLR classes (Kormanik 1986): grade 3 (0 to 3 FOLR), grade 2 (4 to 6 FOLR), and grade 1 (7 or more FOLR). Performance of seedlings in these classes has been monitored in field plantings. After five growing seasons, impact of initial FOLR numbers on yield is striking (table 1). Since sweetgum plantations for fiber production can be harvested between ages 5 to 7, these differences are of practical significance.

The D^2H estimates for yield in table 1 are simply for comparative purposes. Different values would be obtained if harvested stump diameters were used. At the end of 5 years, the grade 1 seedlings have twice as much volume per stem as grade 3 seedlings. More importantly, the yield advantage per tree has been maintained in spite of the 30% greater survival in grade 1 than in grade 3 plots.

During the development of this initial plantation it became obvious that lumping of seedlings into grades prevented us from ascertaining the importance of an individual FOLR. This failure was especially noticeable with the grade 2 and 3 seedlings. Survival and growth varied more among

Table 1.--Initial and fifth year stem diameters, survival, and growth of half-sib sweetgum by first-order lateral root (FOLR) class at planting time[1]

FOLR class	Initial			After 5 years			
	RCD	Height	First-year survival	DBH	Height	Survival	D^2H
	cm	m	%	cm	m	%	cm^3
≥7	1.35a	1.05a	79a	6.5a	5.08a	80a	23705a
4-6	1.14b	1.05a	68b	5.7b	4.72b	65b	17503b
0-3	0.82c	1.03a	50c	4.9c	4.27c	50c	11831c

[1] Mean values within the same column followed by the same letter are not significantly different at *P* = 0.05 according to Duncan's multiple range test.

eedlings in these two classes than among seedlings n the grade 1 class.

In 1986 and 1987 we established two plantations o try and determine the relative contributions to rowth of individual lateral roots from half-sib eedlots. Six different families were used each ear. Both years were excessively dry and this ignificantly affected survival on this upland ite. Approximately 58% of the seedlings outlanted in both drought years survived (table 2). ver 50% of all seedlings with ≤4 FOLR died in the ear they were outplanted, but mortality rapidly eclined with FOLR ≥5.

able 2.--Summary of first-order lateral roots (FOLR) of initial height, root-collar diameter (RCD), number outplanted and percent mortality of half-sib progeny from 12 sweetgum mother trees

umber FOLR	Initial height	Initial RCD	Number outplanted	Mortality
	cm	mm		%
0	88	5.7	80	81
1	96	6.4	128	74
2	100	7.2	224	65
3	102	7.9	265	56
4	104	8.7	281	51
5	105	9.2	280	44
6	105	10.1	258	36
7	106	10.6	250	38
8	105	11.2	196	30
9	106	11.6	136	24
10	104	11.9	116	20
11	106	12.5	96	26
≥12	104	13.7	234	13

In spite of the drought conditions, early growth f surviving trees with ≥5 FOLR has been as good as hat observed in earlier plantings in years with reater rainfall.

Based on our early data, one could conclude that, ther things being equal, sweetgum seedlings with ive or more FOLR have greater potential for fiber roduction in short rotations than do nursery seedlings with ≤4 FOLR. We have no post harvest data on sprout regeneration, but with more uniform survival and larger stems, one might expect better yields from individuals with more FOLR.

Loblolly pine.--For 2 years we have been testing open-pollinated half-sib progeny from mother trees in Georgia Forestry Commission seed orchards. These tests were simply to determine the frequency distribution of progeny by FOLR numbers. The seedlings were not top pruned in the nursery beds. We sampled 100 seedlings from each of two replications for each mother tree to determine the frequency distribution for each half-sib seedlot. Only seedlings with rust or mechanical damage were excluded from our population. Based on an early FOLR distribution model (Kormanik and Muse 1986) we obtained a subsample of two seedlings each from each of four FOLR classes (0-3, 4-5, 6-7, and >8). This grouping was simply an aid in assuring that destructive sampling of seedlings was proportional to their expected occurrence in the population.

Table 3 gives a distribution for 12 half-sib seedlots sown in the Mycorrhizal Institute experimental nursery. These seedlings were rather large by any standard. In fact by many standards they were too large. Even the seedlings in the lowest FOLR class (0-3) were on the average taller (by 50%) and had root collar diameter (4.1 mm) suitable for placement in the middle grade (grade 2) for this species (USDA Forest Service 1985). The seedlings in this class, however, were the least competitive under ideal nursery conditions with minimum competition and may not be as competitive as those with ≥4 FOLR when outplanted. Seedlings with ≤3 FOLR may survive outplanting but may not become dominants or codominants in plantations. This speculation is based on the assumption that the largest seedlings will be the most competitive and the smallest the least competitive as has been observed with sweetgum. Comparable percentages of loblolly pine seedlings with 0-3 lateral roots have been observed in several other experiments at this location.

At a given seedbed density, loblolly pine FOLR distribution appears to be affected little by fertilizer regime, but in-depth studies are incomplete. The effect of FOLR numbers on average

Table 3.--Relationship between number of first-order lateral roots (FOLR) and other morphological traits of 1-0 loblolly pine seedlings from 12 families[1]

FOLR class	Total	Average No. FOLR	Height	RCD	D^2H	Top weight	Root weight	Total weight
	%		cm	mm	cm^3	g	g	g
0-3	36	1.7	39.8	4.1	7.2	10.6	2.0	12.6
4-5	25	4.5	45.4	5.1	12.3	15.9	2.8	21.0
6-7	21	6.4	47.2	5.7	16.1	20.0	3.8	23.8
≥8	18	9.3	49.0	6.5	21.4	26.0	5.4	31.3

[1] Height, RCD, D^2H based on 200 seedlings/mother tree. Destructive weight samples based on 16 seedlings/mother tree.

stem yield may take 5 to 10 more years to determine. Since number of FOLR is significantly related to seedling development in the nursery, I expect it to be an indicator of growth potential on forest environments. The existence and closeness of that relationship will take years to establish.

SILVICULTURE IMPLICATIONS

The importance of a tree's crown position--dominant, codominant, intermediate, or suppressed --is well established. Foresters recognize that variations in growth of individual trees cause some to dominate in natural and planted stands, and they agree that the large and vigorous trees are most profitable to manage.

In the South, a young natural pine stand may contain 20,000 to 60,000 seedlings per hectare. Over the next 50 to 100 years, the number of stems may drop to less than 300. This process of elimination is not well understood or highly predictable, but we know that it occurs.

In planted stands, we provide sufficient growing space for every tree to reach its full merchantable size. At some time in the future we want to sell every tree we plant. Stand and yield tables tell us that we will fail--that yield potential varies widely among the individuals in a stand (Clutter and others 1984; Schnur 1937; USDA 1929). This variation in stem yield is routinely handled as a mensurational problem, but it also has biological implications. Consider the possibility that many individuals are biologically inferior. In the presence of individuals with superior potential, these inferior trees may have little chance of exceeding intermediate or suppressed status. This biological aspect of variations in yield of individual trees has not received enough attention.

If we are going to derive the maximum benefits from artificial regeneration, we must understand the occurrence of intermediate and suppressed trees. If typical progeny from a given mating include superior and inferior individuals, we must find ways to eliminate the inferior ones.

In recent years, inferior seedlings have been identified primarily by stem characteristics and desirable stem characteristics have not changed much in over 50 years. Meanwhile, improvements in nurser technology have altered how seedlings are produced and have significantly affected seedling size. Perhaps, to identify superior seedlings we will have to include a combination of FOLR numbers and stem characteristics. In fact, root morphology may provide the major identifying characteristic of superio seedlings. The idea that a seedling's root system largely determines its suitability for planting is not new. It was well recognized when artificial regeneration was initiated in the United States. Toumey and Korstian (1947) concluded that "in judging quality of nursery stock much greater emphasis should be placed on number, size, extent and condition of roots than on appearance of stock above ground." The relative stability of seedling FOLR numbers over reasonable fertility regimes may in the future permit us to assess seedling competitive potential over a wide range in seedling stem sizes.

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ACCELERATEED AGING:

A POTENTIAL VIGOR TEST FOR LONGLEAF AND SLASH PINE SEEDS1/

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F. T. Bonner; and A. C. Marquez2/

Abstract.--This investigation was conducted as part of a continuing effort to determine the applicability of the accelerated aging technique as a vigor test for southern tree seeds. The technique was effective in differentiating relative levels of seed vigor in longleaf and slash pines. Seed leachate conductivity was linearly and inversely related to germination capacity (vigor), hence this technique can be used as an alternative method of assessing vigor under time constrained situations.

INTRODUCTION

These studies were conducted as part of a ontinuing effort to determine the applicability f the accelerated aging technique as a means for ssessing vigor of southern tree seeds. This aper reports the results on longleaf (Pinus alustris Mill.) and slash pine (Pinus elliottii ngelm.) seeds.

A sensitive measure of the planting quality of eeds is seed vigor which is defined as those roperties which determine the potential for rapid niform emergence and development of normal eedlings under a wide range of field conditions (AOSA 1983). Techniques for measuring tree seed igor have been the subject of intensive investigations (Bonner 1974, 1984a, 1986a, 1986b, Bonner and Vozzo 1982), and these investigations ave provided specific recommendations for a umber of species. One vigor test that shows a ot of promise with tree seeds but has not gained uch attention is the accelerated aging technique f Delouche and Baskin (1973). It is one of the ccepted stress tests for seed vigor largely used ith agronomic crops (AOSA 1983). Its use with tree seeds has been limited to creating different levels of vigor for experimental purposes (Bonner 1974, 1986b). Recently, however, we have demonstrated that accelerated aging can be used effectively with loblolly pine (Pinus taeda L.), water oak (Quercus nigra L.), and pecan (Carya illinoensis K. Koch) seeds (Blanche and others 1988). Although accelerated aging can effectively reduce the vigor of slash pine seeds, we had not successfully shown seed lot differentiation in this species, probably due to the limited number of seed lots used in our previous study. Hence, this investigation was intended mainly to test additional seed lots of slash pine and longleaf pine. Also, this investigation was aimed at assessing the utility of seed leachate conductivity as an alternative vigor test for time-constrained situations.

MATERIALS

Seed Source and Seed Lot Designation

Slash pine seeds (seed lots 43, 44, and 46) were collected in Mississippi by the Forest Service (year unknown) and had germination capacities of 80, 73, and 89 percent, respectively, in 1985. Two additional slash pine seed lots (50 and 55 with germination capacity of 95 percent in 1985 for both lots), both collected in 1985 from a Florida seed orchard and a Mississippi seed orchard, respectively, were subsequently investigated after the test of the three seed lots did not reveal significant seed lot differentiation. Longleaf pine seeds (seed lots 7, 11, and 18) were obtained from the International Forest Seed Company. Seed lots 7 and 11 were collected in 1981 and 1982, respectively. Year of collection of seed lot 18 was not known.

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Accelerated Aging Procedure

Prior to any testing, seeds were surface-sterilized with 2.7 percent sodium hypochlorite and rinsed thoroughly with distilled water. Accelerated aging was performed according to the procedure outlined in the Seed Vigor Testing Handbook (AOSA 1983) with modifications to suit tree seeds (Blanche and others 1988, Pitel 1980). Seeds were placed in Stults accelerated aging containers (24/lot) which are 5.5" x 5.5" x 2" plastic boxes with covers each containing a bronze wire mesh seed holder. Seeds were held in a single layer on this wire mesh over 100 ml of water. The boxes were subsequently placed in a Stults accelerated aging chamber maintained at 41° C and 100 percent RH. Seeds were withdrawn from the chamber at specified time periods (48, 96, 144, 192, 240, and 288 hours) and immediately tested for germination. Unaged seed served as control.

Germination Test

Slash pine seeds were tested for germination using Stults germinators set at alternating night and day temperatures of 20 and 30° C with dark and light regimes of 16 and 8 hours, respectively. Tests ran for 28 days starting immediately after each accelerated aging treatment. Longleaf pine seeds were tested under the same experimental conditions as slash pine except the test duration was for 21 days. The prescribed germination temperature for longleaf pine is a constant 20° C (AOSA 1981) but we found alternating night and day temperatures more effective (Unpublished data from our laboratory). Seeds were considered germinated when the radicle was longer than 1 cm. Germination capacity was expressed as percent of viable seed while peak value, a measure of germination rate, was computed according to Czabator (1962).

Seed moisture content was determined according to Bonner (1979) and monitored following the schedule of accelerated aging. Moisture content determination was confined to longleaf pine seed.

Leachate Conductivity Measurement

Leachate conductivity of slash pine seeds was measured using a multi-probe automatic seed analyzer (Model ASAC 1000), manufactured by Neogen Food Tech, Inc. A sample of 100 seeds from each lot for each accelerated aging period was divided into four equal numbers to correspond to 4 replications (25 seeds/rep.). Each seed was soaked for 24 hours in 3 ml distilled water contained in each of the 100 compartments (compartment volume = 5 ml) of a plastic tray. Seeds were removed prior to reading the leachate conductivity.

Due to a malfunction of the ASAC 1000, the leachate conductivity of longleaf pine seeds was measured using a single probe conductivity meter (YSI Model 35). A replication consisted of 25 seeds soaked in 10 ml distilled water for 24 hours. The leachate was decanted into an appropriate test tube and the conductivity was determined. Unless otherwise specified, all tests and measurements were replicated 4 times.

Statistical Analysis of Data

Regression analysis was used to analyze the data with the intent of defining and quantifying relationships between germination capacity and electrical conductivity, and also between peak value and electrical conductivity. To indicate seed lot differentiation during accelerated aging, data were plotted using 2 standard deviations as error bar.

RESULTS AND DISCUSSION

Slash Pine Seed Lot Response to Accelerated Aging

Slash pine seed lot vigor as reflected by its germination capacity declined with increasing period of accelerated aging (fig. 1B). Seed lots 43, 44, and 46 did not differ from each other with respect to their response to accelerated aging. Hence, it is reasonable to assume that the seed lots are of similar vigor. The high correlation between germination capacity and peak value (fig. 1A) strongly suggests the utility of peak value as a means for indicating or comparing seed lot vigor. Bonner (1986b) found that peak value was the most highly correlated germination variable with most of the vigor tests conducted. All these seem to point to germination rate (germinative energy in older literature) as an indicator of vigor.

Germination capacity and peak value were significantly related to seed leachate conductivity (fig. 2A and B). Both variables were inversely and linearly related to conductivity. A similar relationship has been reported for the same species (Bonner 1986a, 1986b, Bonner and Vozzo 1982, 1986) and other tree species (Pitel 1980). Since electrical conductivity measures the membrane integrity, it should objectively reflect the degree of deterioration of seeds. In fact, the Association of Official Seed Analysts (AOSA 1983) and the International Seed Testing Association (ISTA 1981) have included electrical conductivity as one of the methods of assessing seed vigor in their handbooks. The utility of this technique in evaluating tree seed vigor is accentuated by the rapidity of its measurement, plus the fact that many tree seeds exhibit dormancy, a condition that requires pretreatment before any germination test can be made, thus involving extra time, effort, and cost.

Accelerated aging of two additional seed lots of slash pine (lots 50 and 55) revealed a dramatic seed lot difference with the best seed lot separation occurring at 144 hours (fig. 3A and B). This was true whether germination capacity or peak value was used as the criterion for separation. It was interesting to note again the

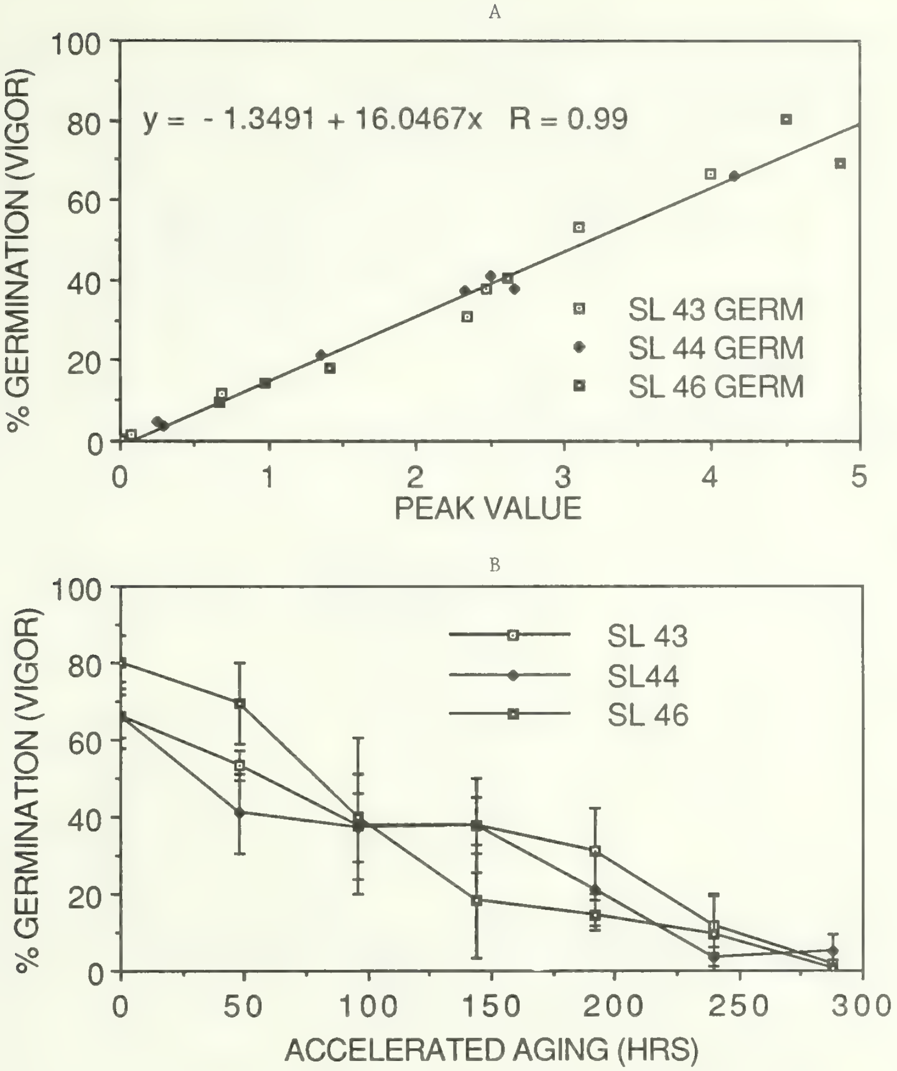

Figure 1.--Decline in germination of slash pine seed lots with increasing period of aging (B) and the quantitative relationship between peak value and germination capacity (A).

enhancement of germination rate as reflected in the increase in peak value at 96 hours of aging (fig. 3A). Such an increase, however, was observed only in the more vigorous seed lot (SL-55). We have earlier reported the enhancement in germination rate in other species by accelerated aging (Blanche and others 1988). Bonner (1984b) likewise observed the same phenomenon in his investigations of accelerated aging of southern pines. It is becoming evident that short periods of accelerated aging may increase germination rate and this may be exploited in achieving more uniform germination as well as shorter periods of germination incubation.

Longleaf Pine Seed Lot Response to Accelerated Aging

The vigor of longleaf pine seed lots declined with an increasing period of accelerated aging (fig. 4A). Although the vigor of the three lots differed initially, the best seed lot differentiation occurred at 96 hours of aging. The increase in germination rate (as depicted by the peak values) of the most vigorous seed lot (lot 7) by accelerated aging periods of 48 and 96 hours (fig. 4B) once again demonstrated the enhancing effect of accelerated aging on germination rate.

The longleaf pine seed moisture content rapidly increased during the first 48 hours of accelerated aging, and then stabilized after 96 hours (fig. 5). In all the tree seeds that we have investigated, the moisture content increased with increasing period of aging. However, the rate of increase in moisture content appeared to differ among species which may be a result of the

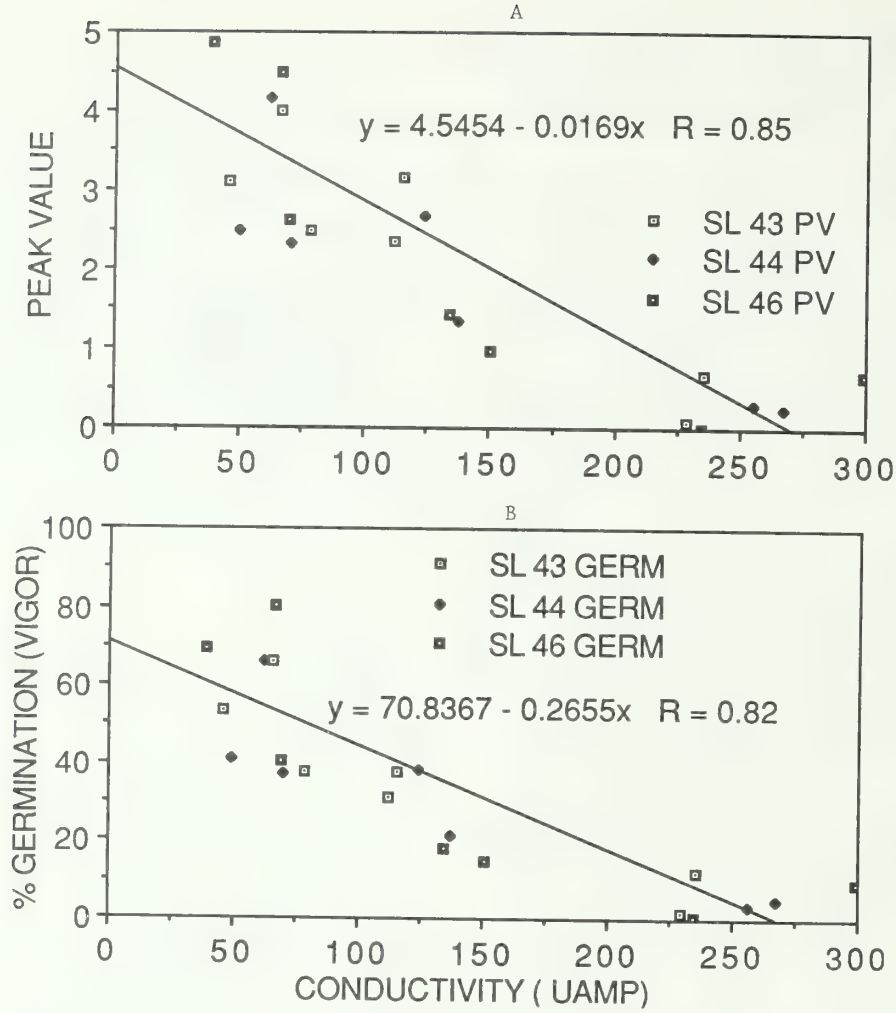

Figure 2.--Quantitative relationships between seed leachate conductivity and germination capacity (B) and leachate conductivity and peak value (A).

differences in the structure of the seed covering, the chemical composition of the storage material, and the initial level of seed moisture. The moisture content of water oak seed (a recalcitrant seed with high initial moisture content) gradually increased during accelerated aging, while pecan seed moisture content increased much more rapidly (Blanche and others 1988). Longleaf pine seed moisture content exhibited the sharpest increase in moisture content among the three, with most of the increase occurring in the first 48 hours of accelerated aging. The intent of monitoring the moisture content was to determine if the increase during aging was contributory to the enhancement of germination rate. Judging from the results there seemed to be little differences in moisture content among the seed lots, although lot 7 (the most vigorous among the three) was consistently higher than the rest, particularly after 48 and 96 hours of accelerated aging. The small differences in moisture content are difficult to translate in terms of germination rate but the fact remains that for a seed to germinate it must first achieve its minimum level of hydration and that a little difference in moisture content can really spell the difference between germinating and not germinating.

Leachate conductivity was significantly related to germination capacity (fig. 6A, B, and C). Of the pine species studied by Bonner and Vozzo (1986) in evaluating seed quality using leachate electrical conductivity, longleaf and loblolly pines exhibited the highest correlation between electrical conductivity and laboratory germination as well as nursery emergence. Our result supports these earlier observations. Judging from all these observations, electrical conductivity of longleaf pine seed leachate can provide a good estimate of seed quality. However, there appears to be a declining linear correlation with decreasing seed lot vigor (fig. 6) which poses some problems in predicting vigor or germination capacity (such as overestimation or underestimation) if the model used was derived from a limited range of vigor classes. For this technique to be functional and to obtain comparable measurements, the procedure must be standardized by taking into

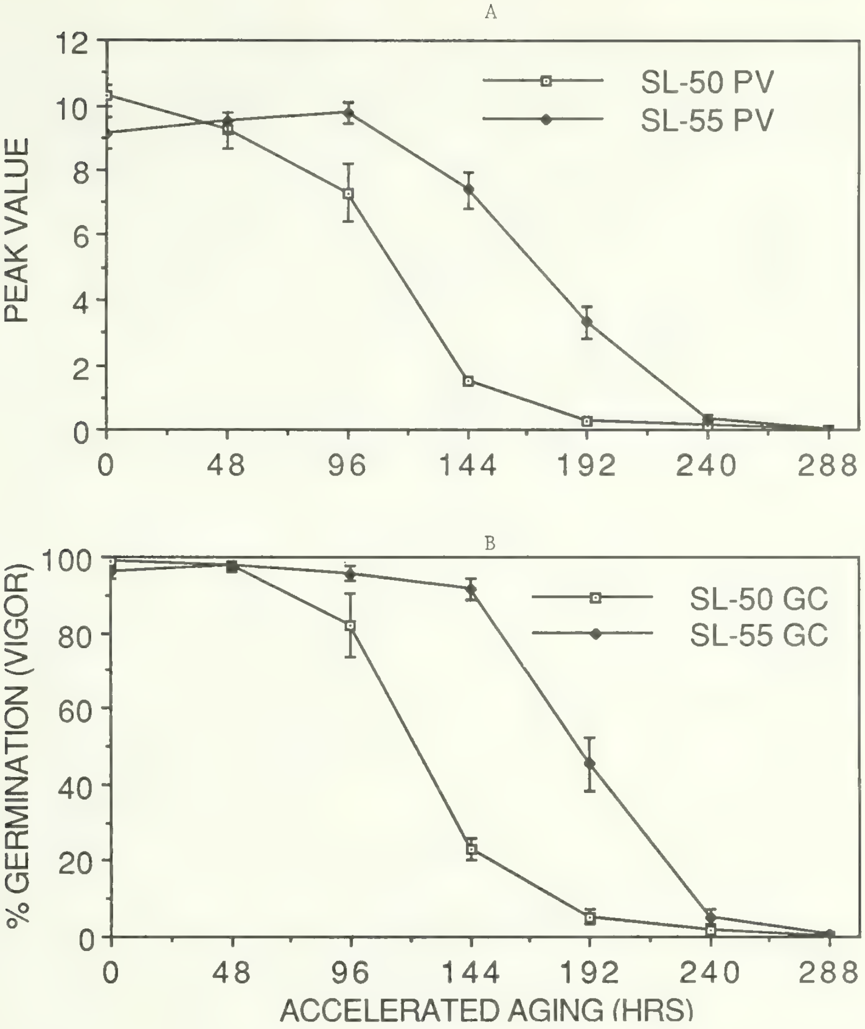

Figure 3.--Differentiation of two slash pine seed lots (50 and 55) with respect to germination capacity (B) and peak value (A) during accelerated aging.

account variables such as instrument type or kind, amount of seed used (weight is better), the volume of distilled water soak, the length of soaking, and other factors known to influence measurement variability.

CONCLUSIONS

Accelerated aging at 41° C and 100 percent RH for 144 hours can be effectively used to identify slash pine seed lots of different levels of vigor. A shorter period of aging (96 hours) is adequate for longleaf pine seed lots.

Seed leachate electrical conductivity can be used as an alternative method of assessing seed quality especially under time-constraining situations. The ease and simplicity of the technique make this method a very attractive means of rating seed lot vigor. Standardization of the procedure is a must if we are to realize meaningful results.

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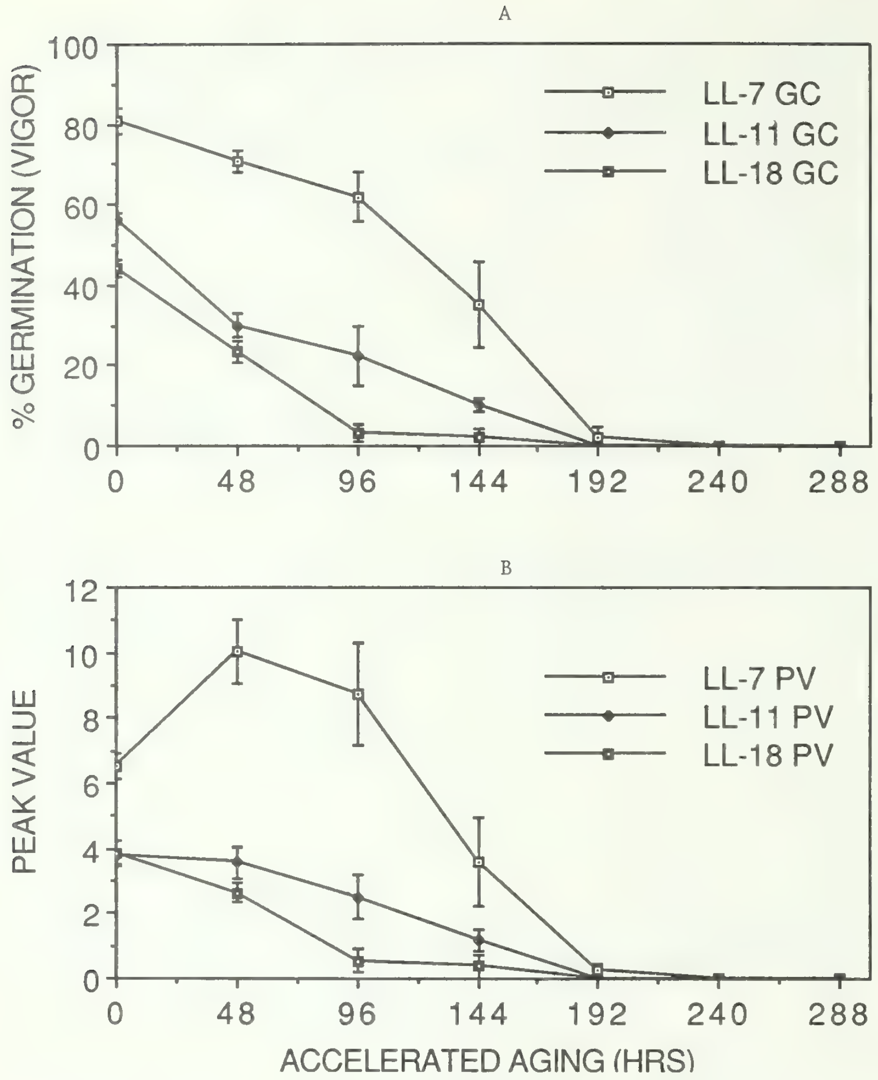

Figure 4.--Longleaf pine seed lot responses to various periods of accelerated aging.

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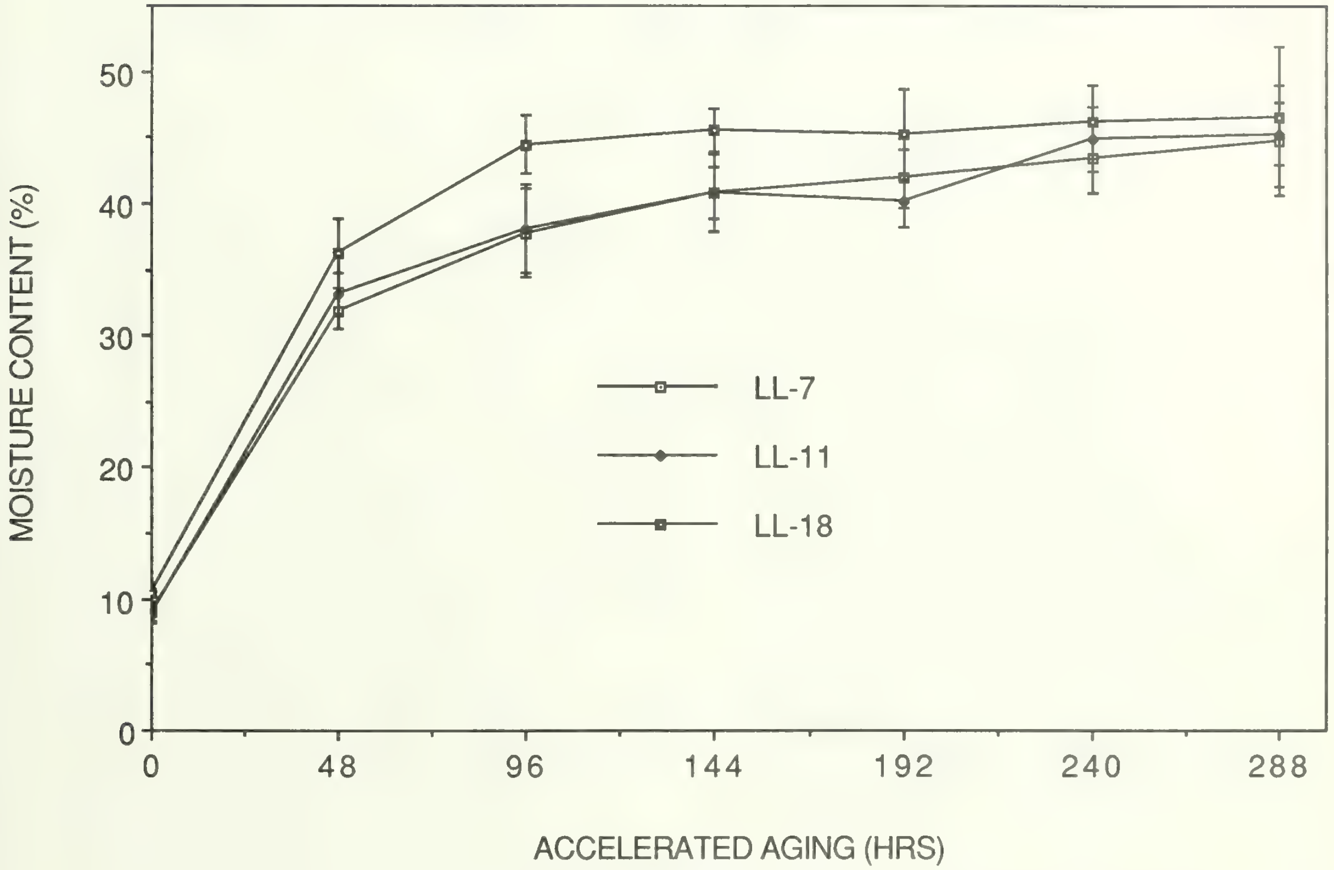

Figure 5.--Changes in longleaf pine seed moisture content during accelerated aging.

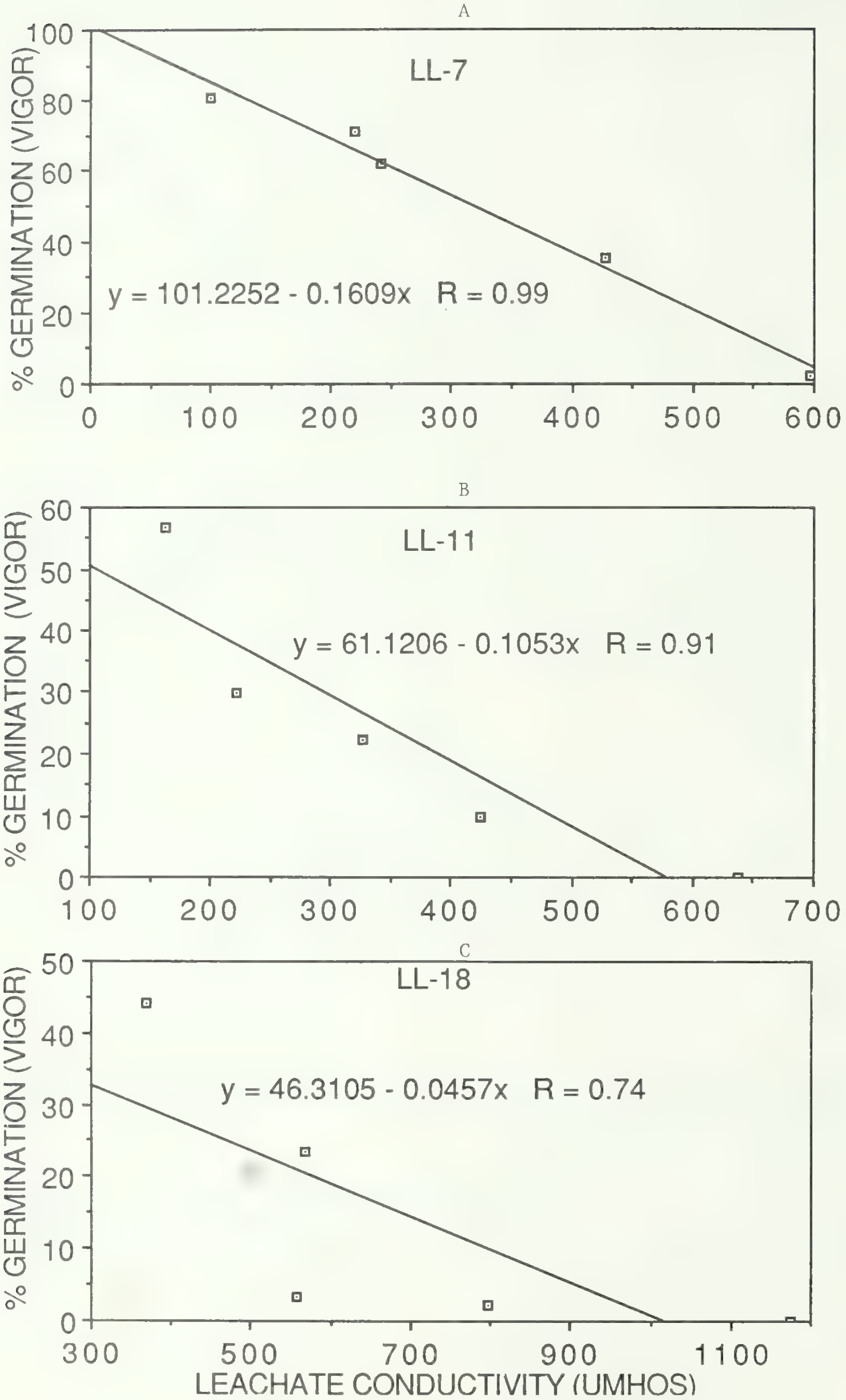

Figure 6.--The relationships between longleaf pine germination capacities and leachate conductivities.

EFFECTS OF SHADE ON THE GROWTH POTENTIAL OF OUTPLANTED YELLOW-POPLAR AND SWEETGUM SEEDLINGS[1]

Hans M. Williams, Ansel E. Miller, and Robert K. Reid[2]

Abstract.--Yellow-poplar (Liriodendron tulipifera) and sweetgum (Liquidambar styraciflua) seedlings were grown in full sunlight and in artificial shade in nursery beds to examine the effects of light preconditioning on field survival and potential growth after outplanting. Two shade experiments were conducted; full sun with 30% shade and full sun with 60% shade. Following growth in the nursery, seedlings were outplanted and received either full sunlight or the same artificial shade treatment used in the nursery. Seedling growth responses to shade were measured in both the nursery and the outplantings. Nursery shade treatments had little effect on field height and diameter growth after outplanting. Outplanting shade treatments had greater effects on field growth. Seedlings outplanted in 30% shade differed little from those in full sun, while seedlings grown in 60% shade had greater height, larger diameters and more biomass than one-year-old seedlings outplanted in full sun. Shading improved growth by reducing water stress and improving seedling water relations. Overall, shading increased establishment and growth of bare-root yellow-poplar and sweetgum seedlings during the first year after field planting.

INTRODUCTION

The effects of shade on seedling growth have been documented for many tree species. Generally, with increasing shade tree seedlings develop larger leaf areas, higher leaf chlorophyll concentrations, smaller root systems, and less total dry weight compared with seedlings in full sunlight (Kramer and Kozlowski 1979). Shade can affect tree seedlings in nursery beds as well as in the field after outplanting. In the nursery, growth in shade would appear to lower seedling morphological grade and reduce quality. However, the final test of nursery seedling quality would be performance after outplanting. In the field, soil moisture can be a limiting growth factor after outplanting. Shade may reduce water stress and could improve seedling water relations (Post 1962, Bonner 1968, Loach 1970, Williams 1983). Yellow-poplar and sweetgum can be classified as moderately tolerant in the seedling stage of growth (Kozlowski 1949, Loach 1970). These species can reach maximum or near-maximum photosynthetic rates at relatively low light intensities. Both species also have indeterminate terminal shoot buds that exhibit continuous growth. Thus, height growth of both species should be a sensitive indicator of environmental conditions in the nursery and field.

The present study was undertaken to measure the effects of nursery shading on survival and growth of outplanted yellow-poplar and sweetgum seedlings. Nursery shade was used to alter planting stock morphology and quality. Because hardwood seedlings planted on open sites may show greater transplant stress and less growth than seedlings planted in shade, the hypothesis that shading improves first-year survival and growth of field planted bare-root seedlings was also examined.

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MATERIALS AND METHODS

Yellow-poplar and sweetgum seed were sown in April and May, 1981, respectively, in beds at the Piedmont Nursery near Salem, South Carolina. The seed were collected locally the previous year. After germination, four 30-foot-long sections of bed for both species were selected at random in the nursery for use as blocks in a randomized complete block experimental design. Seedling density in each block was adjusted by hand weeding to a recommended 12 seedlings per square foot (Williams and Hanks 1976). Each block was further divided in half and fifteen randomly selected seedlings in each half-block were tagged for periodic growth measurements. These seedlings were used to determine monthly height and diameter growth during the growing season. Seedlings of both species were grown to 15 cm in height (40 days) in full sun before a nursery shade treatment was applied in late July. A 30-percent artificial shade treatment was randomly assigned to half of each block. Shade was applied using black plastic shade-cloth (Chicopee Mfg. Co.) suspended 5-feet above each 4-foot wide and 15-foot long half-block using a support made of plastic pipe.

Seedling growth in the nursery was measured to verify the expected shade treatment responses. In August, average seedling leaf surface area was determined with six randomly selected seedlings from each light treatment for all four plots. Leaves were clipped from the seedlings and their surface area measured with a LI-COR 3000 portable area meter (LI-COR INC.). Also, one 2.6 cm^2 leaf disc was removed from the lobe of the fourth mature leaf down from the terminal bud of each seedling to measure chlorophyll content. Chlorophyll was measured using the procedure of Arnon (1949). Nursery seedlings were undercut to an eight inch depth and lifted by block in January 1982. During the lifting operation, 18 seedlings from each light treatment were randomly selected for root dry weight and starch measurements. These seedlings were severed at the root collar and their root systems dried in an oven at 80°C for a minimum of 48 hours. In addition, root starch content was determined by enzymatic hydrolisis using the method of Haissig and Dickson (1979).

Seedlings lifted for field planting were wrapped in moist paper, placed in plastic bags and stored for no more than 2 days in a 4°C cooler. Seedlings of each species were hand planted on the Clemson forest. The planting site was a recently clearcut, rootraked and windrowed mixed hardwood stand that formerly had a high yellow-poplar and sweetgum component.

Four plots were planted for each species. Each field plot contained 240 seedlings from the same nursery block and had 120 seedlings from both nursery light treatments so that controlled variation sources in the nursery were maintained in the field.

A plot consisted of four 60-seedling rows with two rows of each nursery light treatment assigned randomly within the plot. The seedlings were planted at a 1.5 x 1.5 foot spacing.

Each field plot was further divided in half to give two 4-row groups each containing 120 seedlings. Two field light treatments of full sun and 30 percent shade were randomly assigned to each half-plot. Shadecloth identical to that used in the nursery was suspended 6 feet above the outplanted seedlings using 2 x 2 inch wood poles for support. The shade was applied just before bud break in early March. Twenty-five seedlings were randomly selected in each nursery and field treatment combination for both species to measure height and ground line diameter during the 1982 growing season. Survival was calculated using all planted seedlings. A final sample of 12 randomly selected seedlings was excavated in November at the end of the growing season to determine root, shoot and total dry weight. Dry weight increments were calculated by subtracting initial plot dry weight from final plot dry weight.

A second shade experiment similar to that described above was initiated at the Clemson University forest tree seedling nursery a year after starting the first experiment. Yellow-poplar and sweetgum seed were collected in the fall, stratified, and sown in April and May, 1982. All procedures and the experimental design for the nursery were the same as that used in the first experiment except that 60% shade-cloth was used for the shade treatment. Seedling height and diameter growth of each species was remeasured monthly with 15 randomly selected, permanently marked seedlings from each light treatment in all four blocks. Leaf chlorophyll content was measured in mid-August as reported for the 30% shade experiment.

Clemson nursery seedlings in experiment 2 were lifted by hand in January, 1983. Differences in seedling root dry weight and root starch between light treatments were determined as in the 30% shade experiment except that 6 randomly selected seedlings from each light treatment in each block were used as subsamples. Lifted seedlings were stored as in the 30% shade experiment before outplanting. Outplanting was completed within two days. Root growth potential of the outplanted seedlings was determined using another 6 randomly selected seedlings from from each light treatment in each block. Root growth potential was measured using methods described by Williams (1983). Seedlings for experiment 2 were outplanted in other beds at the Clemson nursery. Four beds (plots) were randomly selected for each species. Each plot contained 80 planted seedlings from the same nursery block with 40 seedlings from each nursery light treatment. Therefore, controlled sources of variation in the nursery were maintained in the outplanting. A plot consisted of four rows each having twenty seedlings. Two rows of seedlings from each nursery light treatment were randomly assigned within the plot. The seedlings were planted at a 1.5 x 1.5 foot spacing.

Each outplanting plot was further divided in half to form two 4-row groups containing 40 seedlings. Two outplanting light treatments of full sun and 60 percent shade were randomly assigned to each group. Shadecloth like that used during nursery growth was suspended 6 foot above the outplanted seedlings using plastic pipe for support. The shading was applied just before bud break in March, 1983. All ten seedlings in each nursery treatment and field treatment combination for both species were measured monthly to determine survival, stem dieback, height and ground line diameter as the 1983 growing season progressed. A final sample of 6 randomly selected seedlings was excavated in November at the end of the growing season to determine root, shoot and total dry weight. Dry weight increment was calculated as in the 30% shade experiment.

Analysis of variance for a randomized complete block design was used to test for statistical differences (0.10 level) between treatments for both experiments in the nursery. Seedlings were used as subsamples and plot means were experimental units (table 1). Analysis of variance for a randomized complete block, split-plot design was used to test for statistical differences (0.10 level) for outplantings in both experiments. Whole-block means obtained from seedling subsamples were used to test for nursery light treatment effects in both outplantings (table 2). Split plot means calculated from seedling subsamples were used to test field light treatments.

Table 1. Analysis of variance for detecting differences in nursery light treatment responses for yellow-poplar and sweetgum seedlings (randomized complete block design)

Source		df
Blocks	(Nursery beds)	3
Treatments	(Full sun and Shade)	1
Error	(B x T)	3
Total		7

Table 2. Analysis of variance for detecting differences in nursery and field light treatment responses of outplanted yellow-poplar and sweetgum seedlings (randomized complete block design with split plots)

Source		df
Planting Site Blocks		3
Field Treatments	(Full Sun and Shade)	1
Error A	(Blocks x Field Treatments)	3
Nursery Treatments		1
Nursery Treatments x Field Treatments		1
Error B	(Blocks x Nursery Treatments) + (Blocks x Nursery Treatments x Field Treatments)	6
Total		15

RESULTS AND DISCUSSION

In the nursery, height growth of sweetgum seedlings was similar for sun and shade treatments in both the 30% and 60% shade experiments (fig. 1). Yellow-poplar nursery seedlings also showed small height and diameter growth differences with light treatments during both experiments (fig. 2). Growth appeared more uniform in sweetgum seedlings as compared to yellow-poplar. Although height and diameter were not dramatically altered at the end of the growing season by shade, total seedling dry weight was significantly lower for shade treated seedlings in both experiments (table 3, 4).

Seedling variables used to assess light treatment responses showed that in both species, the 30% light reduction experiment was not severe enough to cause major differences in chlorophyll content per square decameter of leaf surface, root dry weight, or root starch content (table 5). The 30% shade treatment did significantly increase sweetgum seedling leaf surface area, but yellow-poplar had similar leaf areas in both the 30% shade and full sun treatment. The 60% shade experiment showed greater growth differences in both yellow-poplar and sweetgum. Root dry weight was lower in the shade treatment while chlorophyll per square decameter of leaf surface and root growth potential were higher in the shade treatment compared with full sun (table 6). However, root starch concentration remained the same in all light treatments.

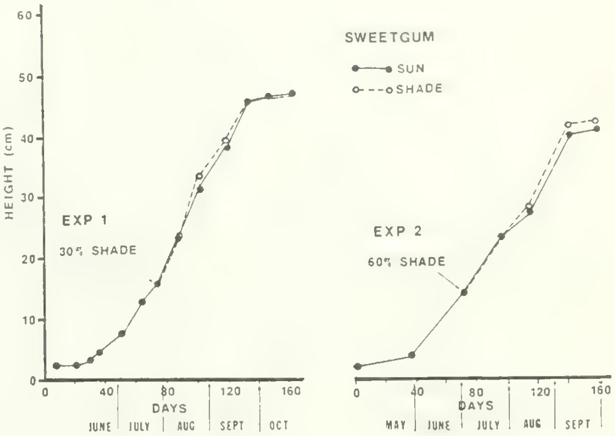

Figure 1.--Seasonal height growth of nursery-grown sweetgum seedlings for Experiment 1 (30% shade) and Experiment 2 (60% shade).

Responses to shade measured in this study are similar to those reported in the literature. Borman (1953) found sweetgum to be tolerant of limited shade, and Post (1962) found greater yellow-poplar growth for shaded rather than unshaded seedlings. Both species have maximum photosynthetic rates at low light intensities (Kozlowski 1949, Loach 1970). In this study, large differences in dry weight occurred in the lowest light (60% shade) treatment. Clearly, seedling morphology and physiology in the nursery were altered using shade treatments.

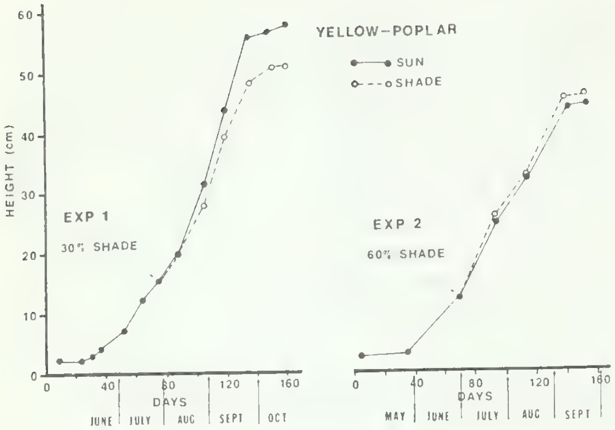

Figure 2.--Seasonal height growth of nursery-grown yellow-poplar seedlings for Experiment 1 (30% shade) and Experiment 2 (60% shade).

Table 3. Height, diameter and dry weight of 1-0 yellow-poplar and sweetgum nursery seedlings grown in full sun and 30% shade

Light Treatment	Height	Diameter	Total Dry Weight
	cm	cm	g
- - - - - - - - Yellow-poplar- - - - - - - -			
Full Sun	56	0.76	5.66
30% Shade	50	0.71	4.56
- - - - - - - - - Sweetgum - - - - - - - - - -			
Full Sun	47	0.62	5.53*
30% Shade	47	0.56	5.20

*Significant at 0.10 level.

Table 4. Height, diameter and dry weight of 1-0 yellow-poplar and sweetgum nursery seedlings grown in full sun and 60% shade

Light Treatment	Height	Diameter	Total Dry Weight
	cm	cm	g
- - - - - - - - Yellow-poplar- - - - - - - -			
Full Sun	46	0.77	5.31*
60% Shade	44	0.67	4.01
- - - - - - - - - Sweetgum - - - - - - - - -			
Full Sun	42	0.54	5.71*
60% Shade	43	0.50	4.52

*Significant at 0.10 level.

Field Performance

Monthly rainfall and temperatures were similar during the two separate years each experiment was outplanted. However, planting site quality differed for the two experiments. The upland clearcut forest area where the 30% shade experiment was outplanted had a clay-loam soil that was less suitable for seedling growth than the soil at the nursery planting site. The sandy-loam nursery soil used for the 60% shade experiment had favorable internal drainage and higher fertility.

Table 5. Leaf chlorophyll concentration and surface area, root dry weight, and root starch of 1-0 yellow-poplar and sweetgum nursery seedlings grown in full sun and 30% shade

Light Treatment	Leaf Chlorophyll[1]	Total Leaf Surface Area[1]	Root Dry Weight[2]	Root Starch[2]
	mg/da^2	m^2	g	%
- - - - - - - - - Yellow-poplar- - - - - - - -				
Full Sun	3.3	0.99	2.33	25.2
30% Shade	3.1	0.93	1.88	24.2
- - - - - - - - - - Sweetgum - - - - - - - - -				
Full Sun	2.8	0.41*	3.34	30.2
30% Shade	2.8	0.49	2.99	29.7

[1] Mid-August measurement.
[2] Mid-January measurement.
*Significant at the 0.10 level.

Table 6. Leaf chlorophyll concentration, root dry weight, root starch, and root growth potential of 1-0 yellow-poplar and sweetgum nursery seedlings grown in full sun and 60% shade

Light Treatment	Leaf Chlorophyll[1]	Root Dry Weight[2]	Root Starch[2]	Root Growth Potential[2]
	mg/da^2	g	%	new root count
- - - - - - - - -Yellow-poplar- - - - - - - -				
Full Sun	2.06*	2.86*	22.9	90*
60% Shade	3.96	1.76	21.0	129
- - - - - - - - - -Sweetgum - - - - - - - - - - -				
Full Sun	2.38*	3.37*	19.1	105*
60% Shade	3.51	2.26	22.0	156

[1] Mid-August measurement.
[2] Mid-January measurement.
*Significant at the 0.10 level.

Periodic height growth measurements of outplanted sweetgum seedlings show the first season of growth was largely complete by June (fig. 3). A similar pattern of height growth occurred with yellow-poplar seedlings (fig. 4). Overall, both yellow-poplar and sweetgum showed better growth in the 60% shade experiment, where the outplanting soil conditions were more suitable than the clearcut forest site.

First-year field survival, height, and root collar diameter of outplanted yellow-poplar seedlings differed by field light treatment in the 60% shade experiment (table 7). No growth differences occurred in the 30% shade experiment. Also, nursery light treatment had little effect on first-year survival, height or diameter in either the 60% or 30% shade experiment. There were no significant nursery-light by field-light treatment interactions in either experiment.

After a year's field growth, sweetgum seedling diameter differed with field light treatment in both the 30% and 60% experiment (table 8). Field survival and seedling height were similar in both light treatments for both the 30% and 60% shade experiment.

Height and dry weight growth increment differed with light treatment. The largest differences in growth increment for both species occurred in the 60% shade experiment. In this experiment, incremental growth in height and dry weight of the root, shoot, and whole seedling were significantly greater for shade treated yellow-poplar and sweetgum seedlings compared to those planted in full sun (table 9). As with first year height and diameter, there was no interaction between nursery and field light treatment growth increments in either the 30% or 60% shade experiment. Survival was high for both species averageing 96% and 99% for yellow-poplar and sweetgum, respectively.

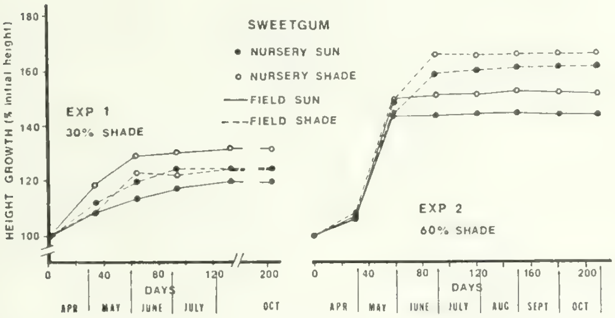

Figure 3.--Seasonal height growth of outplanted, bare-root sweetgum seedlings for Experiment 1 (30% shade) and Experiment 2 (60% shade).

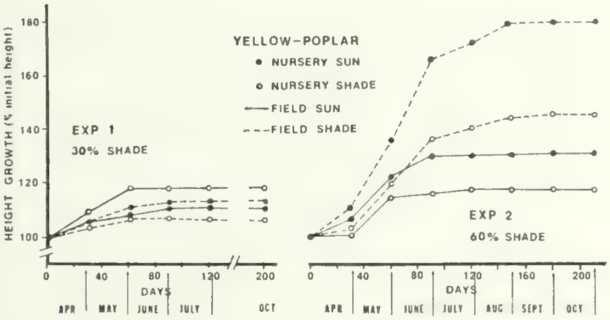

Figure 4.--Seasonal height growth of outplanted bare-root yellow-poplar seedlings for Experiment 1 (30% shade) and Experiment 2 (60% shade).

Table 7. First-year field survival, height, and root collar diameter of outplanted yellow-poplar seedlings by nursery and field light treatments

Light Treatments Nursery	Field	Survival	Height	Diameter
		%	cm	cm
- - - - - - - - 30% Shade Experiment - - - - - - - - - - -				
Full Sun		96	50	0.93
30% Shade		94	49	0.83
	Full Sun	96	50	0.90
	30% Shade	95	49	0.87
- - - - - - - - 60% Shade Experiment - - - - - - - - - - -				
Full Sun		88	59	1.51
60% Shade		91	62	1.45
	Full Sun	88*	49*	0.95*
	60% Shade	100	72	2.00

*Significant at the 0.10 level.

Table 8. First-year survival, height, and root collar diameter of outplanted sweetgum seedlings by nursery and field light treatments

Light Treatments Nursery	Field	Survival	Height	Diameter
		%	cm	cm
- - - - - - - - 30% Shade Experiment - - - - - - - - - - -				
Full Sun		99	58	0.82
30% Shade		99	56	0.82
	Full Sun	98	55	0.76*
	30% Shade	100	59	0.88
- - - - - - - - 60% Shade Experiment - - - - - - - - - - -				
Full Sun		99	60	0.80
60% Shade		97	65	0.80
	Full Sun	96	59	0.72*
	60% Shade	100	66	0.88

*Significant at the 0.10 level.

Table 9. First-year field shoot, root, and total dry weight growth increment for outplanted yellow-poplar and sweetgum seedlings by nursery and field light treatments for the 60% shade experiment

Light Treatments Nursery	Field	Height Increment	Dry Weight Increment Root	Shoot	Total
		cm	g	g	g
- - - - - - - - - - - yellow-poplar - - - - - - - - - -					
Full Sun		21.7	11.0	7.8	18.8
60% Shade		15.8	10.4	8.2	18.6
	Full Sun	10.0*	7.6*	5.9*	13.5*
	60% Shade	27.6	13.8	10.2	24.0
- - - - - - - - - - - - sweetgum - - - - - - - - - - - -					
Full Sun		20.8	10.2	6.2	16.4
60% Shade		24.2	11.1	7.0	18.1
	Full Sun	19.2*	6.7*	5.1*	11.8*
	60% Shade	25.8	14.6	8.1	22.7

*Significant at the 0.10 level.

CONCLUSIONS

Studies have shown that yellow-poplar and sweetgum seedlings of sufficient height and diameter perform well after outplanting (Limstron and Finn 1956, Belanger, et al. 1975, Boyette and Brenneman 1975, Kaszkurewicz and Keister 1975). Although shade decreased dry weight of planting stock in the nursery, height and diameter were largely unaffected by shade. The 30% shade treatment was not adequate to cause differences in growth compared to full sun. Although the nursery shade treatments did not promote favorable planting stock features, nursery conditioning with light had less impact than light conditions in the field.

In the field, planting in shade may improve first year seedling establishment and growth. Shade responses probably reflect reduced water stress and improved water relations. Diurnal water stress (Williams 1983) was found to be less in shaded seedlings compared to those in full sun. Shade treatments in the nursery were not as important as field conditions for the first year after outplanting.

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Site Preparation

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LONG-TERM RESPONSE OF COMPETING VEGETATION TO MECHANICAL SITE PREPARATION IN PINE PLANTATIONS[1]

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Abstract.-- Surveys of plant crown cover on permanently-marked transects and measurements of foliage biomass from separate destructively-harvested biomass plots on two watersheds subjected to quite different regeneration regimes showed quite different post harvest succession through 7 years. Planted slash pine (Pinus elliottii) grew faster on the area which had less competition because of more intensive site preparation. Ecological and economic costs of the gain in pine fiber are described. 3

INTRODUCTION

Mechanical site preparation prior to planting has been an accepted practice for southern pine management for over 20 years. Improved seedling survival and increased growth have been demonstrated for both loblolly pine (Pinus taeda L.) and slash pine (Pinus elliottii Engelm.) over a range of sites, from the Piedmont to the wet savannas of the coast. Site preparation is almost universal in the pine flatwoods where the low relief, sandy soils, and large block ownerships combine to make these sites favorable to mechanized operations.

The objectives of mechanical site preparation on the sandy flatwoods soils are:(1) improvement of microsite conditions (light, moisture, soil physical properties, and nutrient availability); (2) reduction of competition from other vegetation, and; (3) reduction of logging slash and residual vegetation to facilitate planting (Crutchfield and Martin 1982).

Early growth of southern pines can be increased markedly by reduction of woody competition (Cain and Mann 1980, Pienaar and others 1983). Control of competing herbaceous vegetation in young stands of southern pines can also result in growth responses. This has been shown for loblolly pine (Bacon and Zedaker 1985, Cain and Mann 1980, Knowe and others 1985, Nelson and others 1981, Smith and Schmidtling 1970, Tiarks and Haywood 1986) and slash pine (Baker 1973). Long-term reduction in competing vegetation may be more important than widely realized. For both slash pine (Haines 1981) and loblolly pine (Langdon and Trousdell 1974) there is an inverse relationship between the amount of hardwood competition and pine growth. Data summarized by Glover and Dickens (1985) showed that this relationship holds throughout the rotation. Thus, as noted by Burkhart and Sprinz (1984), once hardwood competition becomes established it often remains a constant proportion of the stand growing stock over the rotation, diminishing pine yields. Conversely, the more site preparation reduces hardwoods the less there will be in the plantation and the higher the expected pine yields.

This paper addresses the efficacy of two different site preparation regimes in flatwoods with respect to reduction of competing vegetation and growth of planted slash pine. In particular, the initial reduction in competing vegetation and its regrowth is documented, along with tree growth, over a period of 7 years following regeneration.

MATERIALS AND METHODS

Study Site

The study site is two of three contiguous experimental watersheds in Bradford County, FL-- part of a large (>20 thousand ha) tract of open pineland (68%) and interspersed wooded swamps typical of Coastal Plain flatwoods. The tract had been frequently burned and heavily grazed prior to being acquired in 1938 by Container Corporation of America which instituted fire and cattle exclusion policies and seed tree forest management. Recently maturing pine stands on the tract have been converted to plantations.

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[3] Container Corporation of America provided lands and fire protection, and imposed the prescribed treatments. Dr. Louis F. Conde, deceased, inspired and guided this study from inception through 1984.

On the 67-ha watershed 1 (WS 1), pinelands comprised 49% of the watershed while a shallow, mixed pine and hardwood swamp occupied an interior 51% of the site. On the 49-ha watershed 2 (WS 2), pinelands comprised 74% of the area while several scattered, smaller swamps occupied the remaining 26%. Swindel and others (1982) described soils, typography, climate, and hydrology, and displayed an aerial photograph of these watersheds.

Treatments

Pinelands of WS 1 were clearcut harvested and site prepared by methods deemed to minimize destruction of residual understory, and soil and litter displacement, while permitting machine planting. In November and December 1978, all merchantable (> 10 cm DBH) pine trees were felled, delimbed, sectioned, and stacked by hand for transport from the woods by a small (56 kw) rubber-tired tractor with hydraulic grapple and wood rack. Logging debris and residual vegetation were chopped with a roller drum chopper (Fisher 1981) in April and again in August 1979. Planting beds were formed in September and October by a single pass of a bedding plow (Fisher 1981) and machine planted in November 1979 with a nominal 1,850 1-0 slash pine seedlings per ha. For convenience, we refer to this treatment as minimum site preparation, or minimum treatment.

Pinelands of WS 2 were harvested and site prepared by combining all those methods common in the ecosystem deemed to maximize destruction of residual understory and soil and litter displacement. In November and December 1978, all merchantable (> 13 cm DBH) pine were sheared at the stump with a feller-buncher (Conway 1976) and dragged, crowns intact by large (97 kw) skidders (Conway 1976) to central loading areas where tree length boles were removed to a rail siding. Resin-soaked stumps were excavated and removed with crawler tractors, harvested portions of the watershed were burned in May 1979, and woody debris [and considerable soil (Morris and others 1983)] was pushed into parallel windrows with a large (101 kw) crawler tractor with a shearing blade (Morris and others 1983). Areas between windrows were disked in August with a 3-m-wide offset disc pulled by a crawler tractor-- creating a relatively clean mineral soil surface. Machine bedding and planting was conducted as on the companion WS 1. We refer to this as the maximum treatment.

Surveys

Crown cover for each plant species were recorded in six surveys; one (in the summer of 1977) prior to harvest and five in subsequent summers at plantation ages 1, 2, 3, 5, and 7 years. Survey techniques were described in detail by Conde and others (1983). Briefly, crown cover was repeatedly measured to the nearest dm along vertical projections of 10-m transects and cover was calculated by summation of these values. There were 26 of the 1977 transects within the area subsequently regenerated by the minimum method, WS 1, and 24 transects within the clearcut area on WS 2 regenerated by the maximum method.

Separate surveys were concurrently conducted for biomass (in 1977-78, 1980, 1981, 1982, 1984, 1986). Preharvest overstory biomass was determined by destructive sampling of six 100-m^2 plots. Preharvst midstory biomass was determined by destructive sampling of a 25-m^2 subplot within each plot. Preharvest understory and post harvest biomass (excepting pines) were determined by destructive sampling of several distinct, smaller subplots in each plot (Conde and others 1983). These latter subplots were rotated within plots in successive years (to avoid effects of previous sampling) and comprised 5 m^2 per plot in the 1977-78 survey, 8-m^2 per plot in the 1980 survey, and 6-m^2 per plot in each subsequent survey. Planted pines were not harvested--rather biomass was estimated using equations of Gholz and Fisher (1982).

Cover statistics were much easier to obtain, and are more reproducible in successive surveys, involving as they do remeasurements of permanently marked transects that are not disturbed by observation. Thus, changes in cover (barring recording errors) reflect only changes in the vegetation. Conversely, destructive biomass sampling necessitates movement of field plots in successive years, implying that some variation in successive observations is added due to inherent spatial variation in the stand.

RESULTS AND DISCUSSION

Both watersheds had very similar cover in overstory slash pine and competing vegetation prior to harvesting and site preparation (Table 1). Cover of slash pine has increased at about double the rate on maximum treatment WS 2 compared to the minimum treatment WS 1 following harvest, site preparation, and planting. Although cover of competing trees, shrubs, and vines was reduced substantially by both treatments, the reduction was much greater on WS 2. In addition, the woody competition has recovered much slower on WS 2 where, after 7 years, cover of trees, shrubs, and total woody competition was less than half the level found on WS 1. Only vines were increased on WS 2 and this increase is minor in terms of total woody competition. On WS 1, cover of shrubs and total woody competition has nearly reached preharvest levels after 7 years while cover of woody competition on WS 2 is still well below this level. Unlike woody competition, the herbaceous understory was not diminished by site preparation, but rather was stimulated by clearcutting. This increase in herbaceous cover was due to an increase in grasses on WS 1 and to an increase in forbs on WS 2 where the increase was somewhat greater, especially at ages 3 and 5 years. By age 7 years the cover of herbs had returned to preharvest levels on WS 1, but it was still somewhat above this level on WS 2.

Changes in foliage biomass were somewhat different than for cover. Slash pine foliage biomass was the same through age 7 years on both watersheds as was foliage biomass of competing trees (Table 2). Foliage biomass of shrubs did, however, follow the same trend as shrub cover, recovering more slowly on WS 2 and being less than half that found on WS 1 at age 7 years. Biomass of herbaceous competition increased more following treatment than did the cover of herbs. The increase in biomass occurred in the grasses and to a lesser extent in the forb group on both treatments. Although herb biomass declined over time, it was still about double the preharvest level after 7 years on both watersheds.

Table 1.-- Cover of slash pine and competing species by life form before (1977, 78) and after (1980, 81, 82, 84, 86) harvesting, minimum and maximum site preparation and planting on a north Florida flatwoods site.

Treatment[1]	Cover					
	'77-78	'80	'81	'82	'84	'86
	percent					
	Slash pine					
Minimum	57.2	0.3	0.6	4.1	12.1	17.5
Maximum	58.7	0.5	3.0	9.3	17.8	27.0
	Competitive trees					
Minimum	10.6	1.7	3.1	2.5	3.2	4.4
Maximum	13.7	0.2	0.2	0.5	1.0	2.0
	Shrubs					
Minimum	81.5	18.4	21.8	33.5	57.2	71.0
Maximum	77.2	3.3	9.2	16.9	27.6	25.3
	Vines					
Minimum	1.4	0.1	0.3	0.3	1.1	1.8
Maximum	1.4	0.1	0.1	0.6	3.4	6.0
	Total woody competition					
Minimum	93.5	20.2	25.2	36.3	61.5	77.2
Maximum	92.3	3.6	9.5	18.0	32.0	33.3
	Grasses					
Minimum	35.7	27.7	39.3	41.2	41.9	31.6
Maximum	30.1	19.7	23.2	33.9	39.1	39.1
	Grasslikes					
Minimum	3.0	4.4	2.0	1.4	1.6	0.4
Maximum	3.3	11.0	5.9	5.4	3.5	1.8
	Forbs					
Minimum	7.1	6.9	8.0	9.7	8.2	3.6
Maximum	3.4	9.2	21.4	23.5	25.2	12.8
	Ferns					
Minimum	1.0	0.7	0.9	0.9	1.9	4.7
Maximum	1.3	0.3	0.1	0.2	0.4	0.1
	Total herbaceous					
Minimum	46.8	39.7	50.2	53.2	53.6	40.3
Maximum	38.1	40.2	50.6	63.0	68.2	53.8

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[1] Minimum treatment consisted of clearcutting, chopping, bedding, and planting. Maximum treatment was clearcutting, stump removal, burning, shearing and piling, discing, bedding and planting.

Table 2.-- Foliage biomass for slash pine and competing vegetation by life form before (1977, 78) and after (1980, 81, 82, 84, 86) harvesting, minimum and maximum site preparation and planting on a north Florida flatwoods site.

Treatment[1]	Foliage biomass					
	'77-78	'80	'81	'82	'84	'86
	kg/ha					
	Slash pine					
Minimum	4787	12	22	704	1333	2306
Maximum	4524	21	128	194	1236	2069
	Competitive trees					
Minimum	326	0	11	3	12	7
Maximum	373	3	1	6	7	15
	Shrubs					
Minimum	1811	436	634	1008	1698	1340
Maximum	1291	454	389	600	730	533
	Vines					
Minimum	4	25	8	28	109	147
Maximum	35	3	3	9	218	139
	Total woody competition					
Minimum	2141	461	653	1039	1819	1494
Maximum	1699	460	393	615	955	687
	Grasses					
Minimum	148	917	960	1385	769	369
Maximum	339	1458	762	992	954	577
	Grasslikes					
Minimum	15	188	66	58	15	3
Maximum	3	560	83	61	24	14
	Forbs					
Minimum	21	224	206	252	102	20
Maximum	36	504	593	427	122	55
	Ferns					
Minimum	18	52	15	24	17	8
Maximum	4	0	1	7	2	7
	Total herbaceous					
Minimum	202	1381	1247	1719	903	400
Maximum	382	2522	1439	1487	1102	653

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[1] Minimum treatment consisted of clearcutting, chopping, bedding and planting. Maximum treatment was clearcutting, stump removal, burning, shearing and piling, discing, bedding and planting.

Maximum site preparation controlled woody competition better than the minimum treatment. The cover data indicates the slash pine responded to the reduction in woody competition on WS 2 and this response should continue for a few more years because the woody competition is still at a lower level. The growth response by slash pine is also apparent in height and diameter data. At age 7 years, mean diameters and heights were 7.82 cm and 5.8 m on WS 1, and 8.58 cm and 6.5 m on WS 2. The lack of an apparent response in the biomass data is likely due to the smaller sample size and greater variation (cf. Surveys).

In the South deficient soil nutrients limit pine growth on many forest soils and are not available at low moisture levels (Glover 1985). The reduction of competition results in an increase in pine growth because moisture, nutrients, and light are made available for use by pines rather than competing species. Although inherent site quality is not changed by competition control, it can result in a more efficient capture of the potential tree growth. This results in a shorter rotation age as it takes less time to reach a selected product size or total volume of wood. On the basis of the cover data pines on WS 2 are about 1 year ahead.

Mechanical site preparation normally increases rather than reduces herbaceous competition (Nelson 1978), and the more intensive the treatment generally the greater the response by the herbs. Fortunately, the herbaceous species decline rapidly as the woody species take over, soon returning to preharvest levels. All of these trends are quite evident in the cover and biomass data from this study. Thus, both treatments may have created a short-term negative response for pine growth by increasing herbaceous competition.

Often when one component of the competition is reduced it will result in a corresponding increase in another component (Cain and Mann 1980). This did occur to a degree on WS 2 where herbaceous competition increased more than on WS 1. The amount of increases, however, was not as large as the reduction in shrubs, and overall competition was less, as shown by the increased growth of the pines on this treatment.

As noted earlier, long-term pine growth in plantations is closely related to the proportion of hardwood trees in the stand. The relationship is curvilinear and even relatively low levels of competing hardwoods can substantially reduce pine yields (Glover and Dickens 1985). For example, the model by Burkhart and Sprinz (1984) predicts an increase in competing hardwood basal area from 10 to 30% would decrease pine yield by 75%. On the basis of cover, WS 1 is 80% slash pine and 20% competitive hardwood trees, while WS 2 has 93% and 7% slash pine and competing hardwoods, respectively. It is hard to relate this to past work which is all based on the percent of hardwood basal area. However, if the reduction in the hardwood component lasts, pine yields at rotation age should be greater on the maximum treatment.

Past studies have shown a general trend of decreasing competition in subsequent pine stands as the intensity of the site preparation increases (Haines and Pritchett 1965, Schultz 1976, Schultz and Wilhite 1974). Therefore, the better control of competition and greater pine growth on WS 2 could be expected. However, the maximum treatment is not the better of the two unless the greater pine growth justifies the extra costs. Based on data from Straka and Watson (1985) the maximum treatment costs about $90 more per acre than the minimum treatment. This is a substantial amount and a less-expensive chemical treatment may have given similar competition control and pine growth. In addition, the growth advantage on WS 2 and the extra growth that could be expected because of less hardwood competition may be offset before rotation age is reached due to nutrient deficiency-caused growth loss, which commonly occurs after about age 10 when crown closure takes place. This is quite likely on WS 2 because of the movement of large quantities of nutrients into the windrows where they are largely unavailable for pine use (Morris and others 1983). Therefore, even though maximum site preparation does give better competition control which results in greater initial pine growth, its high cost and potential for subsequent nutrient deficiency-caused growth loss appear to make it undesirable. Long-term growth data are needed before this is known for certain.

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SURVIVAL AND COMPETITION RESPONSE FROM SEASONAL VARIATION IN DISKING TREATMENTS[1]

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Abstract.--Two year survival and competition level results were measured on a seasonal disking study. A control plot with three seasonal disking treatments represent the study with all other variables being held constant. Significant differences in survival and competition levels demonstrate the value of considering seasonal scheduling in site preparation prescriptions.

INTRODUCTION

Since the sixties, three-pass mechanical site preparation (shear, rake-pile, and disk) has been one of the primary methods used to regenerate cutover Piedmont land to loblolly pine (Pinus taeda L.) The disking phase of this treatment has three primary functions:

-- To reduce competing vegetation;

-- To improve soil aeration;

-- And to increase planting quality through better root orientation.

Foresters have long been concerned about the significance of disking season on plantation survival and growth, but little information is available on the subject. Those opposed to dormant season disking argue that competition control is less and the risk of soil damage is greater during the winter months. Others maintain that the benefits of a limited disking season are minimal and insufficient to justify the associated logistical problems and increased cost of a time limited season. A study was initiated in 1984 in an attempt to help resolve this question. Specifically, the objectives were:

a. To compare the effects of a shear-rake operation alone and in combination with winter, spring and summer disking.

b. To formulate operational scheduling guidelines for disking in the site preparation process.

METHODS

Study Site

The study was located on a "typical" Piedmont site in Oglethorpe County, Georgia. The dominant soil type was Georgeville intermingled with small patches of Herndon and Kirksey. An SCS soil scientist visited the site and confirmed that these soils should be consistent in tillage and loblolly pine growth.

Establishment and Layout

Three blocks of approximately twenty acres each were laid out to minimize variation in slope and aspect within replications. Blocks were further divided into five acre plots. One of four treatments were randomly assigned to each plot. Treatments tested (and timing) were:

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Research and Development Supervisor, Silviculturist, and Resource Analysis, Champion International Corporation, Greenville, S.C.

a. Shear-rake only (August 1985)

b. Shear-rake (March 1985) and disk (March 1985)

c. Shear-rake (March 1985) and disk (May, 1985)

d. Shear-rake (March 1985) and disk (August 1985)

All plots were operationally machine planted by a contractor in the 1985-86 planting season. Trees were of the same genetic source, improved loblolly, and were planted over all plots in a short period of time to minimize variation due to planting.

Measurements

Soil moisture percent and residual debris levels were sampled immediately prior to disking to establish operating conditions associated with each treatment. Following planting, eight 1/10 acre sample plots were randomly located in treatment blocks and initial stocking was tallied. In August 1987 these plots were revisited to measure second year pine survival and hardwood stems per acre. These data were evaluated through analysis of variance with treatment differences tested using Duncan's New Multiple Range Procedure. The arcsin transformation was used to normalize the distribution of survival percentages.

RESULTS

Pre-disk Conditions

Results from the soil moisture and residual material audits are presented in tables 1 and 2

Table 1.--Soil moisture percent immediately prior to disking.

Treatment	R1	R2	R3
Winter Disk	20.8	23.9	20.1
Spring Disk	20.1	21.9	19.2
Summer Disk	16.4	17.4	17.2

As indicated in table 1, soil moisture conditions were well within operational limits for each disking operation. The small variation among replications likely reflect differences in aspect and slope, while the decline in moisture content from winter to summer can obviously be attributed to seasonal weather patterns. Moisture variations were not high enough to substantially affect tillage or risk damage to soil from heavy equipment.

Table 2.--Average pre-disk residual material volume (Cubic ft/a)

Treatment	R1	R2	R3
Winter Disk	55	276	60
Spring Disk	5	70	7
Summer Disk	115	89	70

Similarly, the residual debris survey depicted in table 2, indicates a very "clean site". Even the highest level of residual material (276 cubic feet per acre) is a very small amount of debris for a large disk in a site preparation operation. It is doubtful that there was enough material on any treatment plot to have had a significant impact on disk penetration.

Second Year Pine Survival

Average survival ranged from 49 percent for the winter disk to 77 percent for the August treatment. The two-pass (undisked) and spring disk were intermediate at 64 and 72 percent respectively. These differences show a trend and are statistically significant (alpha = 0.10 table 3). To pinpoint the cause of survival differences (fig. 1 and 2) between treatments is beyond the scope of this study, but there are several possibilities.

Second Year Hardwood Survival

Hardwood densities range from moderately high to low after the second growing season and they appear to follow the inverse pattern of that described for percent pine survival (table 4 and figure 2 and 3). That is, highest densities for winter disking and lowest densities for summer with spring being intermediate.

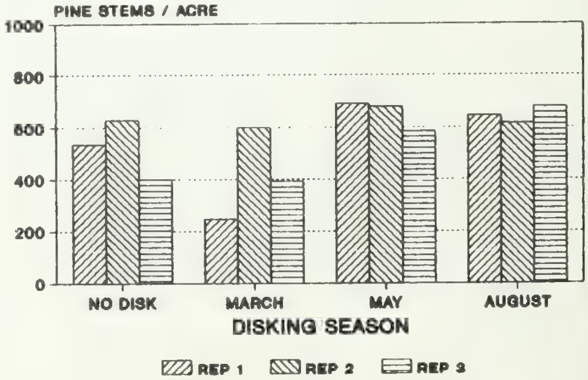

Figure 1.--Second year pine survival per acre by replication and treatment.

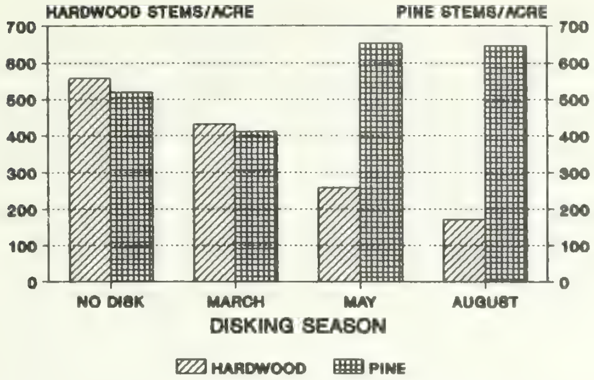

Figure 2.--Average pine and hardwood stems per acre are by treatment season.

Table 3.--Effects of disking season on second year pine survival --average of three replications

Treatment	Initial stocking	Surviving stems	Survival[1]
	trees/a	trees/a	percent
No Disk	818	520	64 b
Winter Disk	842	412	49 c
Spring Disk	904	652	72 ab
Summer Disk	842	646	77 a

[1] Different letters within columns indicate significant differences among treatments at the 10 percent level.

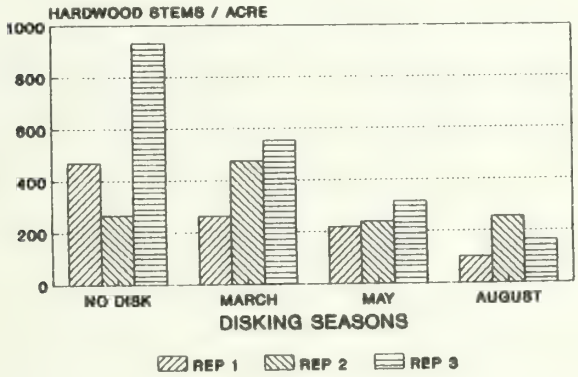

Figure 3.--Second year hardwood rootstocks per acre by treatment and replication.

DISCUSSION

Pine Survival

Pine survival percentages are statistically different with summer and spring disking being rated best 77 percent and 72 percent, no disking rated second 64 percent, and winter disking as least desirable 49 percent (see table 3). One of the reasons for this difference seemed visually to be related to herbaceous competition. Effects of herbaceous competition are complicated by application timing. Plots disked early in the year were exposed to a full growing season prior to planting which will obviously give weeds a head start. This timing does, however duplicate operational practices in the field. Sites disked after December 31 are not planted until the following season due to excessively loose soil.

Possible reasons for the amount of herbaceous competition are related to timing. Winter disking will bury some seeds below germination depths, but it will create ideal seed bed conditions for many others and promote their rapid growth. A spring treatment will destroy many plants that have already germinated, but favor the later species. In August, virtually all weed species will have germinated, but hopefully only a few will have produced seeds for the next year. It seems reasonable then to assume that herbaceous weed control will be most effective with summer disking, least with a winter treatment, and intermediate when it is done in spring. The effects of first year weed control on loblolly pine growth and survival have been visually demonstrated in numerous weed control plots in the Southeast, and a similar relationship is a likely cause of some early survival differences here.

Hardwood Competition

Second year hardwood figures in this study indicate a strong correlation between disking season and plantation hardwood densities. March, May, and August disking seasons had hardwood densities of 431, 259, and 173 stems per acre respectively (see table 4 and figure 3). This is similar to that described by Cathey and Sloan[1] (1986) and shown in figure 4 in a survey of hardwood stems per acre in operational plantations conducted in the same area.

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[1] Cathey, T.N., Sloan, S.L., 1986, Unpublished research note, Champion International Corporation.

Although surviving pine stems increase as hardwood stems decrease there is no clear evidence at this age as to the degree to which the two are related. There is however circumstantial evidence that shading by large clumps of hardwoods and water use by high hardwood densities would affect pine survival.

Table 4.--Effects of disking season on second year hardwood competition --average of three replications

Treatment	Hardwood[1]
	stems/a
No Disk	556 a
Winter Disk	431 ab
Spring Disk	259 bc
Summer Disk	173 c

[1] Different letters indicate significant differences among treatments at the 10 percent level.

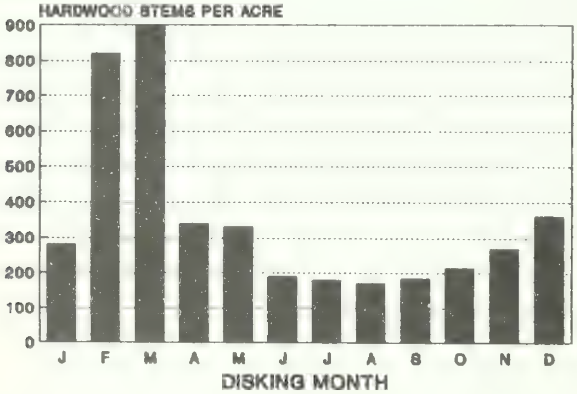

Figure 4.--Average hardwood stems per acre in operational pine plantations by disking season. (Cathey and Sloan 1986)

Soil Physical Properties

Treatments that were disked should have higher rates of water infiltration than the control plots that were not disked. This extra water could affect the pine survival in a normal precipitation year and most probably would in a droughty year.

CONCLUSIONS

Pre-disk moisture levels indicate that tillage immediately following treatments can be consistent in quality for winter, spring or summer disking. Pre-disk moisture levels also indicate that disking can be accomplished in the winter at levels similar to summer conditions, which should not cause compaction problems.

Pine survival and hardwood competition however, was affected by seasonal disking. Pine survival was significantly higher with summer disking, intermediate in the spring, and low in the winter and hardwood rootstock numbers had significant but opposite results. Visually herbaceous competition also was affected with high levels of competition in the winter and low in the summer.

Although the mechanisms involved cannot be positively identified, the results are clear. The effectiveness of site preparation disking as measured by seedling survival and hardwood control was significantly affected by disking timing in this study. Survival and hardwood control both have a profound impact on plantation growth and yield, and ultimately on economic returns realized from regeneration investments.

THE IMPACT OF WINDROWING ON THE PRODUCTIVITY OF A ROTATION AGE LOBLOLLY PINE PLANTATION[1]

T.R. Fox, L.A. Morris, R.A. Maimone[2]

Abstract.--A 3 acre tract in the North Carolina Piedmont was site prepared in 1954 by piling logging slash into windrows. An adjacent area was site prepared by broadcast burning the logging slash. Both areas were then planted with loblolly pine (Pinus taeda L.) seedlings. Total volume production through 31 years was 5167 cubic feet per acre in the nonwindrowed plantation compared to 3987 cubic feet per acre in the windrowed plantation; a 23 percent reduction. Site index (base age 25) in the interior of the windrowed plantation was 11 feet less than in the nonwindrowed plantation.[3]

INTRODUCTION

Reduction of logging slash and control of the vigorous hardwood sprouts that often follow harvesting are essential for successful regeneration of pine plantations in the Piedmont. Site preparation regimes which include piling of logging slash into windrows are common throughout the South. A 1982 survey of regeneration practices in the South found that 34 percent of the sites planted in that year had been windrowed (APA 1985).

Windrowing substantially reduces the amount of slash on a site and thereby improves access for future management activities such as planting. When discing follows windrowing, as is common on Piedmont sites, soil physical conditions are also improved (Gent et al. 1984), and hardwood sprouting may be reduced. This combination of increased ease of planting, improved soil conditions and initial competition control often results in increased survival and early height growth in windrowed vs nonwindrowed Piedmont plantations (Lantagne and Burger 1982).

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Research Assistant, Soil Science Department, University of Florida, Gainesville, FL 32611; Assistant Professor, School of Forest Resources, The University of Georgia, Athens, GA 30602; Laboratory Research Specialist, Department of Forestry, North Carolina State University, Raleigh, NC 27695.

[3] This study was initially installed by T.E. Maki and we are fortunate to be able to continue the work started by Dr. Maki over 3 decades ago. We acknowledge the detailed work done previously on this site by George Glass that prompted our interest in remeasuring the study. We also thank Larry Jervis for providing records of the management history of these stands. Paper No. 10494 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC 27695.

The advantages of windrowing are often apparent the first few years after planting; however, there are disadvantages associated with windrowing that may not show up until later in the rotation. Repeated travel of heavy equipment over the site can compact the soil and inhibit root growth (Greacen and Sands 1980). A substantial portion of a sites nutrient capital may also be lost when slash is piled into windrows (Morris et al. 1983, Tew et al. 1984). This may lead to nutrient deficiencies at a later time in the established plantation (Vitousek and Matson 1985).

Although the "windrow effect" of increased growth of seedlings planted in close proximity to windrows is commonly observed, growth of seedlings farther away from the windrows can be significantly reduced. On the basis of measurements in a seven year old plantation of Pinus radiata in New Zealand, Ballard (1978) estimated that windrowing would cause site index decline of 6.5 feet. Fifth year results from a study of slash pine (Pinus elliottii) growth on a windrowed site in the flatwoods of Florida showed that trees growing remote from the windrows were approximately 2 feet shorter than those growing adjacent to the windrows (Swindel et al. 1986).

In 1954, a 3 acre tract in the North Carolina Piedmont was site prepared by piling logging slash into windrows while an adjacent tract was site prepared by broadcast burning. Early results from this study were reported by Haines and coworkers (1975) and Glass (1976). At age 20 the nonwindrowed area supported 11 more cords per acre than the windrowed area. Trees adjacent to the windrows were significantly larger in height and diameter than trees in the rest of the plantation. This present paper summarizes growth of these two stands through 31 years and provides an indication of the effects of windrowing in the Piedmont on loblolly pine stands approaching rotation age. Because of the lack of information on the long term impacts of windrowing on site productivity, and because the previous reports from this study have been widely cited, we believe an update on the results from this case study will be of interest to forest managers in the South.

MATERIALS AND METHODS

This study was conducted in the Piedmont in Durham County, North Carolina. Soils in the study area were Georgeville silty clay loams (Typic Hapludults, clayey, kaolinitic, thermic).

The original objective of this study was to determine if windrowing, in contrast to broadcast burning, would eliminate the need for future release treatments of the planted pine. The amount of brush growth on the windrowed site was not sufficient to warrant a release treatment in contrast to the broadcast burned area which did require a release cutting. However, this site also provides 2a case study of the effects of windrowing on long term tree growth in the Piedmont.

Merchantable timber on an 8 acre site was logged in October 1953 and nonmerchantable stems were felled during the winter of 1953-1954. In March 1954, logging slash on a 3 acre portion of the site was piled into two windrows by a crawler tractor equipped with a toothed blade. The windrows were located parallel to each other approximately 200 feet apart an occupied 11 percent of the site. Glass (1976) estimated that 2 inches of topsoil had been displaced from the interior of the site to the windrows along with the logging slash. The windrowed area was planted with loblolly pine at a 6 x 6 ft. spacing in April 1954. The windrows were not burned or planted. This stand was prescribed burned in 1968, 1972 and 1977 and a thinning in 1979 removed 1204 cubic feet/acre. The remaining 5 acres of the site, located directly across a woods road from the windrowed area, was site prepared by burning the logging slash in March 1954. This site was planted with loblolly pine at a 6.5 x 6.5 ft. spacing in April 1954. A release cutting was carried out in this stand to free the planted pine from overtopping hardwoods during the second growing season. In 1971, a fertilization study was installed on the majority of the nonwindrowed site; however, a portion of the stand was excluded from the fertilization study so that growth between the windrowed and nonwindrowed stands could be compared. The excluded portion of the stand was prescribed burned in 1978 and in 1979 a thinning removed 1653 cubic feet/acre.

The study was remeasured in February 1985, 31 years after establishment. In the windrowed area, three 0.1 acre circular plots were established adjacent to the windrow with their plot centers approximately 25 feet from the edge of the windrow (windrow-adjacent plots). Three 0.1 acre circular plots were also established in the interior of the windrowed area approximately 100 feet from either windrow (windrow-interior plots).

Because of space limitations in the nonwindrowed area imposed by the aforementioned fertilization experiment, only one 0.1 acre circular plot could be established which was certain to be free of edge effects (nonwindrow plot). To estimate per acre productivity on the windrowed site, including the relative contribution of trees adjacent to the windrow and those in the interior of the stand, two 20 ft. wide transects were established from the center of one windrow to the center of the second windrow. In each circular plot and the transects, d.b.h. and total height of all stems greater than one inch d.b.h. were measured. Individual total tree volume of each loblolly pine was calculated using the following equation (Burkhart et al. 1981):

$$\text{Volume} = 0.11691 + 0.00185(D^2H).$$

Hardwood volumes were also calculated but are not presented because hardwoods comprised less than 5 percent of the volume in any plot.

One dominant or codominant loblolly pine in each circular plot was selected for stem analysis. The selected tree was felled, limbed, measured for total height and bucked into 1.5 ft. sections. Age at the stump and at the small end of each section was determined by counting annual rings. The stem analysis data were used to construct a height vs age curves.

Five composite samples of the surface six inches of the mineral soil, excluding forest floor material, were collected from each of three locations: 1) in the actual windrow; 2) 100 feet from the edge of the windrow; and 3) in the nonwindrowed plantation. The soil samples were air dried and ground to pass a 20 mesh screen. Extractable cations and CEC were determined by the North Carolina Department of Agriculture Soil Testing Service using the Mehlich 3 extraction procedure (Mehlich 1984). Soil pH was determined on a 1:1 soil:water suspension. Mineralizable soil nitrogen was determined by a modification of the aerobic incubation procedure of Stanford and Smith (1972) developed by Maimone (1988).

Because this report deals with a nonreplicated case study, conventional statistical tests of significance were inappropriate (Hurlbert 1984). Therefore, mean values and standard deviations were used to summarize the data.

RESULTS AND DISCUSSION

The difference in the size of trees adjacent to the windrows compared to those in the interior of the windrowed stand was large (fig. 1). The "windrow effect" of increased tree height extended only a limited distance into the interior of the stand. Total height of loblolly pine in the windrowed plantation decreased rapidly as distance from the windrow increased resulting in the familiar "wave like" pattern of tree height across the plantation.

Trees in the windrow-adjacent plots averaged 9 feet taller and 2 inches greater in d.b.h. compared to trees in the windrow-interior plots (table 1). The differences were even greater when only the dominant and codominant pine in the two sets of plots were compared. Trees in these crown classes in the interior of the windrowed plantation were more than 12 feet shorter and 2.5 inches smaller in d.b.h. than those adjacent to the windrow. The average tree size was greater in the nonwindrowed plantation than in either set of plots from the windrowed plantation. However, dominant and codominant loblolly pine growing in the nonwindrowed plantation were similar in size to the dominant and codominant pine growing in the windrow-adjacent plots. This change in plot ranking was due to the distribution of tree size across the windrowed plantation illustrated in figure 1. The area of the windrow-adjacent circular plots extended from approximately the center of the windrow to approximately 65 ft into the interior of the plantation. The larger trees in the windrow-adjacent plots were all located in the half of the plot nearer to the windrow while the trees in the half of the windrow-adjacent plots remote from the windrow were much smaller. The trees growing under conditions similar to the interior of the windrowed area caused a decrease in the average tree size of the windrow-adjacent plots.

The differences in height of dominant and codominant trees at age 31 resulted in a decrease in site index of 11 feet in the interior of the windrowed plantation. Using equations developed by Amateis and Burkhart (1985) for the Piedmont, the site index (base age 25) in the interior of the windrowed plantation was calculated to be 55.7 feet compared to 65.6 feet adjacent to the windrow and 66.2 feet in the nonwindrowed plantation.

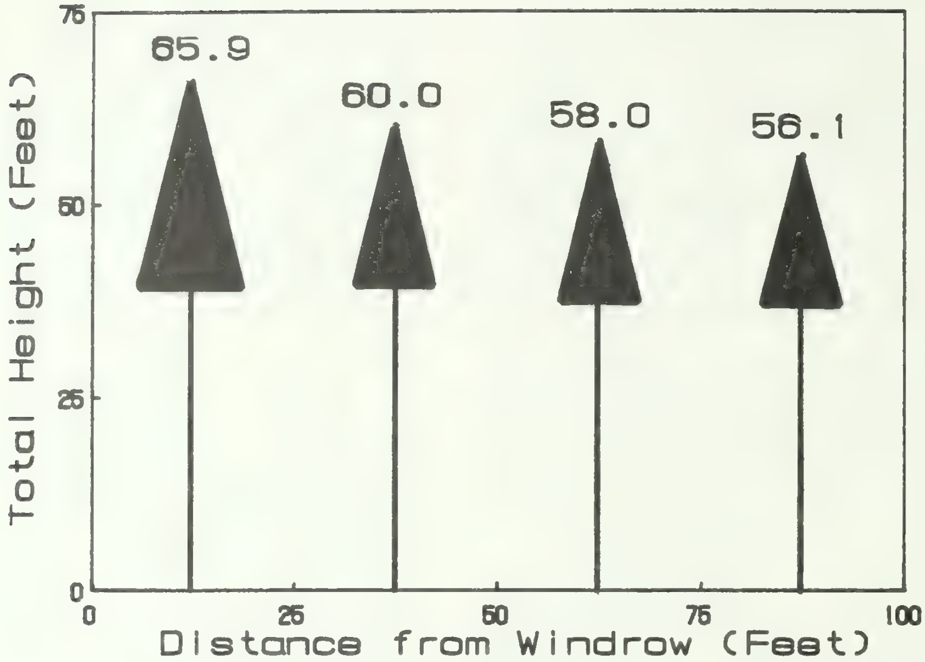

Figure 1.--The effect of distance from windrow on total height of loblolly pine in the North Carolina Piedmont at age 31.

Table 1.--Height and d.b.h. of loblolly pine in two plantations in the North Carolina Piedmont at age 31

Plantation	All pine		Dominant and codominant	
	Height	d.b.h.	Height	d.b.h.
	(feet)	(in)	(feet)	(in)
Windrowed site:	[1]			
interior plots	55.2(5.6)	7.1(1.4)	65.4(1.3)	9.2(1.0)
adjacent plots	64.4(7.5)	8.8(0.9)	77.6(3.5)	10.7(2.5)
Nonwindrowed site:	71.0(4.3)	10.4(0.9)	78.3(0.3)	11.1(0.4)

[1] Mean values are followed by standard deviations in parentheses.

Stem analysis data showed that the height growth patterns of all trees were similar through age eight (fig. 2). Beyond age eight, height growth of trees adjacent to the windrows and in the nonwindrowed plantation continued at similar, relatively rapid rates. However, height growth of trees in the interior of the windrowed plantation slowed considerably beyond age eight.

Total per acre volume production data from this study indicates that the productivity of the windrowed site has decreased (table 2). Volume production determined from the transect data and including the material removed in the 1979 thinning was 23 percent less on the windrowed site than the nonwindrowed site. These figures are quite close to the yield predictions made for thinned loblolly pine stands with the observed site indices (Smith and Hafley, 1984).

Table 2.--Volume production through 31 years in two loblolly pine plantations in the North Carolina Piedmont

Plantation	Standing volume	Total volume[1]
	(cubic feet/acre)	
Windrowed	2783	3987
Nonwindrowed	3514	5167

[1] Total volume includes volume removed during 1979 thinning.

The faster growth of trees adjacent to the windrow did not compensate for the slower growth of trees in the interior of the stand. Since the "windrow effect" of apparent faster growth extended only a limited distance into the stand interior, total per acre volume production was less on the windrowed site. Comparison of the

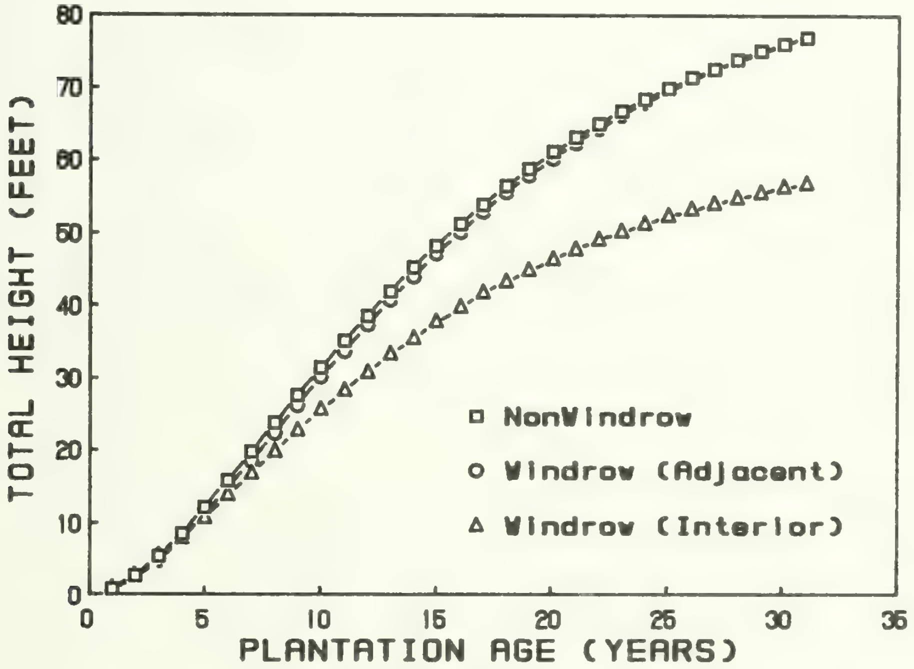

Figure 2.--Height vs age relationships for 31 year old loblolly pine in the North Carolina Piedmont.

growth of trees near the windrow with trees on the nonwindrowed site shows that at least on this site the "windrow effect" in not actually caused by increased growth near the windrows but rather was a result of decreased growth of trees in the interior of the stand (fig. 1; fig.2; table 1).

Glass (1976) conducted a detailed investigation into the causes of the growth differences in these two plantations at age 20. He found that approximately 2 inches of topsoil had been displaced into the windrows. As a result there were significant differences in the nutrient status of the soils in the two plantations. Extractable nutrient levels were higher in the windrows than in the interior of the stand where the soil had been scraped. Soil nutrient levels in the nonwindrowed plantation were higher than in the interior of the windrowed plantation but lower than in the actual windrows. The fact that there were no apparent differences in soil bulk density between the nonwindrowed site and the interior of the windrowed site led Glass (1976) to concluded that the observed differences in tree growth were due to differences in soil nutrient availability.

In 1985, we resampled the soils in the two plantations to find out if these nutrient differences still existed. The same trends observed by Glass (1976) were found in our samples (table 3). The soil nutrient data at age 31 supports the conclusion that the slower tree growth on the windrowed site was caused by reduced nutrient availability. The lowest soil nutrient concentrations occurred in samples from the interior of the windrowed site. Soil nutrients in the nonwindrowed plantation were at slightly higher levels. Much higher levels of soil nutrients were found in the windrows themselves. The higher nutrient concentrations in the soil from the windrows can be attributed to the nutrients in the slash and topsoil moved from the interior of the stand. Morris and coworkers (1983) reported that over 350 lb/ac nitrogen and 160 lb/acre Ca were displaced to the windrows on a flatwoods site in Florida while over 600 lb/acre nitrogen were displaced to the windrows on a Piedmont site (Tew et al. 1984).

It has been theorized by several workers (Burger 1979, Vitousek and Matson 1985) that the effects of nutrient loss during site preparation will not become apparent until several years into the rotation. The most likely period is near the time of crown closure when the nutrient demand of the developing stand is greatest. The height growth patterns obtained from the stem analysis data (fig. 2) support this hypothesis. All trees grew similarly until about age eight, the time near which they would be approaching maximum nutrient demand. After age eight, the trees in the interior of the windrowed plantation where the nutrient reserves were lowest began to fall behind in height growth.

Table 3.-- Soil nutrient status in two loblolly pine plantations in the North Carolina Piedmont at age 31

Plantation	N [1]	K	Ca	Mg	CEC	pH
	(ppm)	(ppm)	(ppm)	(ppm)	(meq/100 g)	
Windrowed Interior: [2]	73(10)	103(16)	275(22)	79(7)	4.9(0.2)	5.2(0.1)
Windrow:	95(7)	150(44)	1649(756)	208(121)	11.4(4.6)	6.4(0.4)
Nonwindrowed:	83(7)	95(10)	375(73)	84(28)	5.4(0.5)	5.1(0.1)

[1] Potentially mineralizable nitrogen determined by a long term incubation procedure (Maimone 1988).

[2] Mean values are followed by standard deviations in parentheses.

Although nutrient differences appear to be the primary cause for the observed growth differences, other factors may be involved. Glass (1976) found no differences in soil bulk density at age 20. However, soil compaction may have occurred during site preparation in the windrowed area that was ameliorated by age 20 by natural factors such as soil freezing and thawing. If this were the case, initial growth of seedlings on the windrowed site would be expected to be slower. However, no discernable differences in height growth patterns were found prior to age eight (fig. 2) suggesting that the effect of any soil compaction was relatively small.

Differences in hardwood competition existed in these two stands that may have affected tree growth. The need for a release cutting in the nonwindrowed plantation at age two suggests a much more severe competition problem existed in this stand. At age 31, the windrowed stand was practically free from understory competition except in the actual windrows. There was a considerable understory component in the nonwindrowed stand. The greater competition in the nonwindrowed plantation would most likely have reduced the growth in this stand compared to the windrowed stand where the hardwood competition was less. However, since the nownwindrowed stand was already growing more rapidly than the windrowed stand, the difference in volume production presented in table 2 would probably be even greater if the hardwood competition in the nonwindrowed stand had been eliminated. Thus, although differences in hardwood competition may have affected tree growth, it is unlikely they would affect the conclusions from this study concerning the productivity declines associated with windrowing.

SUMMARY AND CONCLUSIONS

The results from this study indicate that windrowing has detrimentally impacted productivity on this Piedmont site. It appears that differences in nutrient availability were the primary cause for the observed differences in tree growth. The fact that the soil nutrient differences still exist at age 31 also suggests that nutritional problems may persist into the next rotation. On this Piedmont site, windrowing may have caused a productivity decline that is essentially permanent unless corrective action, such as fertilization, is taken. In light of these results, site preparation prescriptions for Piedmont sites that include windrowing should be carefully reviewed. To prevent the kind or productivity declines observed in this study, site preparation activities should be directed toward conserving the nutrient reserves of the site.

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SIXTH YEAR RESULTS FROM A STAND REGENERATION PROJECT[1]

T.N Cathey, J. L. Torbert, J. A. Burger, and G. O'Conner[2]

Abstract.--Sixth year growth responses are reported for a large site preparation study established in the Piedmont of South Carolina and Georgia in 1980. Positive correlations between treatment intensity and growth are still present, but differences in relative volume have diminished since age three. Changes in site preparation strategy and techniques over the past six years are also discussed for an industrial timberlands organization.

INTRODUCTION

Prior to World War II most artificial regeneration of southern pines was confined to abandoned agricultural lands which had been under intensive annual cultivation for decades (Haines and others 1975). During the last forty years, however, increased demand for forest products and expansion of the industry southward has dramatically intensified pressures on the region's timber resource. Consequently, foresters have been challenged to search for practical and cost-effective methods to prepare cutover sites for regeneration. The prevailing assumption has been that the ultimate silvicultural objective in site preparation is to duplicate the "old field" conditions that were so successful in early reforestation efforts. This assumption has been reinforced by an observed correlation between site preparation intensity and early plantation success, a correlation that may be misleading since the success of a thirty-year investment in regeneration is frequently judged after the first growing season.

Since initiating regeneration efforts on cutover land in the mid 1960's, foresters in Champion International's Western Carolina Region have relied heavily on a mechanical site preparation method which consists of three passes; KG shearing, raking debris into windrows, and disking. The prescription has resulted in the establishment of thousands of acres of well-stocked, high-volume plantations, but research has indicated that there may be risks of long term site damage associated with operations of this intensity.

Although sketchy, results from several studies demonstrate that high-intensity operations required to approach "old field" conditions can adversly affect long-term site productivity and reduce timber yields for initial and subsequent rotations. Pehl and Bailey (1983) evaluated the effects of chopping, disking, and bedding on a cutover site in the Georgia Piedmont through age ten. Height growth during the first three years was strongly correlated with treatment intensity, but the advantage of bedding had disappeared by the end of the tenth growing season, and the authors speculated that gains achieved from disking would be lost by age 25. Other research indicates that root raking can be particularly damaging. The disturbance and soil movement associated with this operation can produce a decline in available nutrients (N and P), topsoil losses, and compaction (Morris and Lowery 1988). Glass (1976) compared the effects of rootraking and site preparation burning on a twenty-year-old stand and found that raking had resulted in a two inch loss of topsoil. Concerns over site degradation, increasing treatment costs, and harvesting on steeper terrain prompted foresters in the Western Carolina Region to question the wisdom of continuing a site preparation program that relied exclusively on a single intensive mechanical prescription. In an attempt to address these questions Champion International and Virginia Polytechnic Institute and State University (VPI) initiated a study in 1980 to evaluate alternative site preparation methods for the regeneration of loblolly pine in the Piedmont of Georgia and South Carolina. The overall objective of the study is to attempt to find and implement site preparation methods which:

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Silviculturist, Champion International Corporation, Greenville, SC; Associate Professor, Research Associate, and Graduate Research Assistant, respectively, VPI&SU, Blacksburg, VA.

--Minimize site preparation costs;

--Maximize plantation survival, growth and yield; and

--Maintain or increase long term site productivity.

PROCEDURES

Study Sites

Twelve Piedmont study sites were selected with four in each of the following Champion land management areas: Washington, GA; Newberry, SC; and Winnsboro, SC (figure 1). Soils are typical for the Piedmont with various phases of the closely related Appling, Cataula, Cecil, Hiwassee, and Pacolet series represented. Most have been severely eroded from past agricultural practices leaving heavy clay subsoils at or near the surface. Site indices (base age 50) range from 60 to 90 feet, and stand volumes averaged 2,209 cu ft of pine and 222 cu ft of hardwood per acre prior to harvest.

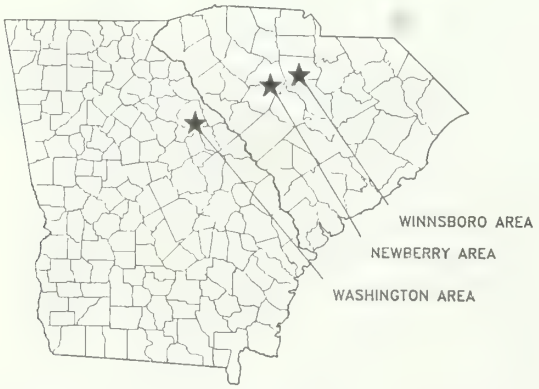

Figure 1.--Stand regeneration project study locations in Georgia and South Carolina.

Establishment and Layout

In order to credibly simulate operational-scale treatments, an area of approximately 40 acres was set aside at each of the 12 locations. Site characterization sampling and clearcutting were completed in the summer of 1980 and treatments imposed that fall. Treatment blocks ranged from four to seven acres each, with an additional plot at each location left uncut for future comparisons. The six treatments listed below were selected to provide a range of feasible regeneration systems of varying intensity and cost.

a. Control (harvest, plant without site preparation);

b. Chop and burn (chop with a tandem offset chopper followed by a broadcast burn);

c. Shear and disk (KG shearing and disking in a single pass);

d. Shear and rake-pile (KG shearing followed by a separate rake and pile operation with no disking);

e. Shear, V-blade and disk (KG shearing in one pass followed by disking on the second pass with a V-blade mounted on the front of the tractor); and

f. Shear, rake-pile and disk (KG shearing in one pass, followed by raking and windrowing in the second pass, and a third operation for disking).

Sites were planted in early 1981 with genetically improved seedlings produced at Champion's nursery in Swansea, SC. Control plots were planted by hand and all others by machine. Target spacing was 10 ft by 6 ft (726 SPA) with actual initial stocking ranging from 322 to 871 SPA. Five 0.1 acre measurement plots were randomly located on each treatment to monitor survival and growth.

Measurements

Within each 0.1 acre subplot, tree diameter, and height were recorded after the first, second, third and sixth growing seasons. Diameters were measured at ground line for the first three years and breast height at age six.

RESULTS

Survival and Growth

Sixth year survival ranged from 42 percent on the control plots to 70 percent for the one-pass disk (table 1 and figure 2). The three disked treatments led the others in survival, but were statistically superior only to the control plots. First year survival was poor due to a severe drought during the spring and summer of 1981, but very little additional mortality has occurred through age six. The low initial stocking for the one and two-pass disking treatments is probably due to debris interference during machine planting, a problem that could be corrected operationally with experience.

Table 1.--Trees planted, trees surviving at age six, and sixth-year survival percentage by site preparation method.[1]

Treatment	Planted	Remaining	Survival
	Trees per Acre		Percent
Control	641	270	42 b
Chop/Burn	607	360	59 a
Windrow	618	365	59 a
1-pass-disk	597	416	70 a
2-pass-disk	533	346	65 a
3-pass-disk	645	408	63 a

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[1] Different letters within columns indicate significant differences among treatments at the 5 percent level.

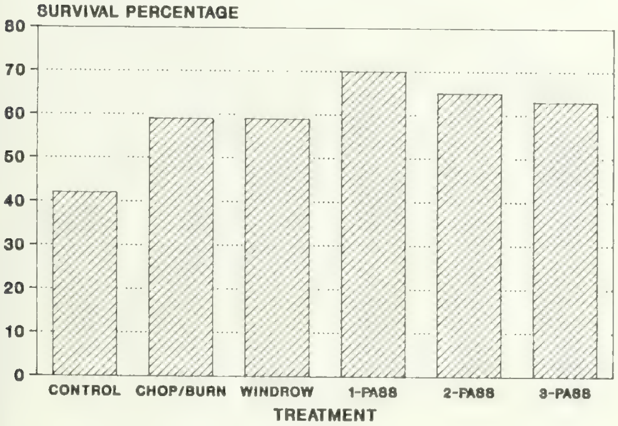

Figure 2.--Six year survival percentage by treatment.

Values for average heights and diameters at age six closely paralleled site preparation intensity, but differences among the three disking treatments were small and not statistically significant (table 2).

Table 2.--Effect of site preparation on pine height and diameter growth after six years[1]

Site Preparation	Tree Growth Height	D.b.h.
	(feet)	(inches)
Control	10.8 d	1.6 c
Chop & Burn	12.0 bc	2.2 ab
Windrow	11.8 c	2.0 b
1-pass disk	12.7 ab	2.2 ab
2-pass disk	12.6 ab	2.3 a
3-pass disk	13.0 a	2.3 a

---

[1] Different letters within columns indicate significant differences among treatments at the 5 percent level.

Average individual tree volumes for each treatment at ages three and six are compared in table 3. At age three, volume indices for disking treatments were all significantly higher than the other four, and the three-pass led all six. Sixth-year data indicate dramatic changes in relative growth performance. The three-pass treatment continues to lead in average tree volume, but its advantage over the two-pass, one-pass, and chop-burn is no longer statistically significant. This change in relative treatment performance from age three to age six has important operational implications. The first three years are often looked upon as the "establishment phase" of regeneration, and it is assumed that adequate stocking and vigorous growth at that point translate to a successful plantation. Data summarized in table 3, however, indicate that three-year results may not accurately predict future plantation performance.

Table 3.--Comparison of average tree volumes by treatment at ages three and six years[1]

Treatment	Average Tree Volume Age Three	Age Six
	(in^3)	(in^3)
Control	45.19 d	131.33 c
Chop & burn	100.76 c	221.18 ab
Windrow	85.19 c	195.26 b
1-pass disk	119.42 b	245.38 a
2-pass disk	122.05 b	248.83 a
3-pass disk	150.83 a	259.20 a

---

[1] Different letters within columns indicate significant differences among treatments at the 10 percent level.

Age three volumes were calculated using the following formula:

$V = D^2H$, where;

V - individual tree volume index,
D - ground-line diameter,
H - total stem height.

For age six volumes, the following formula was used:

$V = (3.14/3) \times (D.b.h/2)^2 \times H$, where;

V - individual tree volume,
D.b.h. - diameter breast height,
H - total height.

In order to graphically represent the changes in treatment performance over the first six years of the study, individual tree volumes were converted to relative volume (RV) using the following formula.

$RV = 100\ (VT-VC)/VC$, where;

RV - Percent improvement over control,
VT - Average treatment tree volume,
VC - Average control tree volume.

Relative volume is simply a measure of the percent improvement for each treatment over the control at each measurement age (one, two, three, and six years). The value for the control treatment will always be zero and will lie on the horizontal axis when graphed.

As illustrated in figure 3, differences between treatments peaked around age two or three and appear to be converging by age six. Particularly noteworthy is the trend toward convergence of the one, two, and three-pass volumes between ages three and six. If this trend continues, the average individual tree volumes for the less intensive treatments may actually equal or exceed the three-pass method in future years (Burger and Crutchfield 1986).

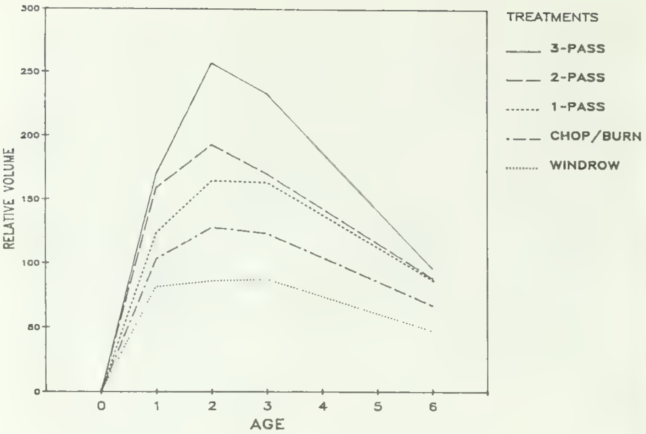

Figure 3.--Relative volume over age for five site preparation treatments.

OPERATIONAL APPLICATIONS

Continued pressures to control site preparation costs, concern over site degradation, and early successes of the less intensive methods in this study have led to dramatic changes in site preparation strategy for Champion International's Western Carolina Region. Encouraged by relatively high survival of the one and two pass treatments after the first three growing seasons, Region foresters began experimenting with these and modified methods on an operational scale during the mid 1980's. Emphasis has been on examining various combinations of shearing, burning, disking, and chopping for the many variations of site and post-harvest stand conditions encountered in the Piedmont. Due to the cost and detrimental effects of raking, the philosophy has been to reduce its use to the lowest level possible, and utilize alternative methods to handle debris. Careful observation of successes and failures in survival and competition control on the different treatments and varying site conditions has enabled Region foresters to develop expertise and confidence in making site specific prescriptions.

The research, operational trials, and observations have resulted in the evolution of a totally new strategy for site preparation on the 12,000 acres treated annually in the Region. A system that relied almost exclusively on a single high intensity shear, rake, disk method has been replaced by one that utilizes a number of different treatment combinations with the objective of attaining successful stand establishment with minimal site damage at reasonable cost.

A summary of annual treatment acreages for the Washington, Georgia Area (figure 4) demonstrates how fully the strategy has been implemented. In 1978, for example, 100 percent of the 3745 acres prepared for planting in the Area was sheared, raked, and disked. The 1989 plan lists only 32 acres, or less than 1 percent of the total, to be three-passed.

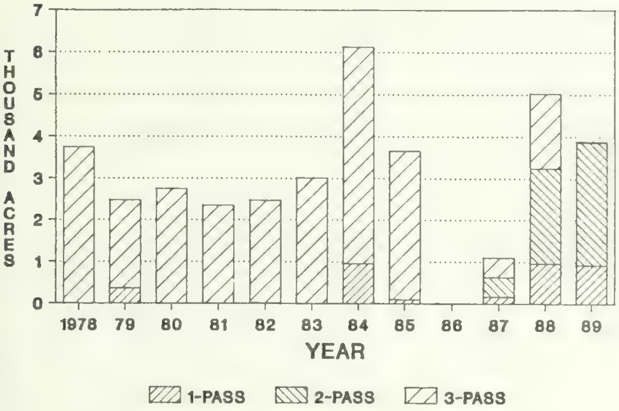

Figure 4.--Washington site prep summary-annual acres by treatment intensity.

One area forester has identified seventeen separate treatments which may be appropriate for the varying conditions encountered in the Piedmont of eastern Georgia (Sloan 1988). These treatments and descriptions of site and stand conditions where each could be considered are presented in Appendix A. In addition to the expansion in mechanical methods, the utilization of current herbicide technology is expected to increase, particularly on those sites where even low intensity equipment operations are detrimental.

CONCLUSIONS

The six year results from this site preparation study must be considered preliminary within the context of 25- to 35-year rotations. Early growth figures do, however, indicate that equivalent levels of success in stand establishment can be attained without the expensive and potentially damaging raking pass. It is too early to make long term growth projections for the various treatments, but there is a trend for early differences among the three disking treatments to diminish. These differences may become negligible or possibly even reversed by harvest age.

The most significant point concerning this study may not be within the formal structure of the project itself, but rather in the relationship between research and the operational needs of a forest products organization. The idea originally grew from a common interest of VPI staff members and Champion foresters in pursuing different options for site preparation prescriptions. Implementation was a cooperative effort, with the two organizations working together in study design, and Champion providing the land, equipment and personnel resources for treatment installation. VPI staff members have conducted most measurements and analysis during the regeneration phase of the study with financial support from Champion. As results have become available, field foresters responded with operational tests of study treatments and other methods they believed might be appropriate for specific site conditions. After several years of evaluating numerous successes and failures, forest managers have developed enough expertise and confidence to prescribe these treatments on a routine basis.

The current philosophy certainly does not represent a final answer to site preparation in the Piedmont. Future programs must be continually modified in accordance with new findings from this and other studies, operational results, and management objectives.

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APPENDIX A

Site Preparation Guidelines for Pine Regeneration

Washington Area -
Washington, Georgia
Stephen L. Sloan

September 1988

Natural Regeneration.--Little or no vigorous hardwood competition. Minimal soil compaction, rutting, etc. Well stocked stand of desired species.

Plant Only.--Little or no hardwood or pine competition. Few obstructions. Sandy soil with little or no rutting.

Burn Only.--Little or no vigorous hardwood competition (fire will control young pine competition). Moderate levels of debris (tops) on ground. Sandy soil with little or no rutting.

Shear Only.--Steep slopes where soil disturbance may cause erosion. Will control residual pine stems. Low levels of heavy debris. Little or no vigorous hardwood competition. No serious compaction problem. Poor sites where preservation of organic matter is crucial. Sensitive areas where use of fire and chemicals is inappropriate.

Shear, Burn.--Same as Shear only except: 1) Less erosion potential (slope and soil). 2) Higher levels of debris. 3) Hardwood competition levels low to moderate.

Chop Only.--Same conditions as Shear Only, except that chopping could help break up debris to facilitate machine planting.

Chop, Burn.--Same as Shear Burn, but chopping will improve burning where a greater fire intensity is needed.

Herbicide, Burn.--Vigorous hardwood or herbaceous competition. No serious compaction problem. Erosion or operability constraints. Absence of sensitive areas nearby (environmental or social). Significant ground obstructions. Soil conditions appropriate for hand planting.

Herbicide Only.--Same as above, except: 1) Minimal obstructions. 2) Need to preserve organic material. 3) Fire restrictions.

Shear-Disk (1-pass).--Little debris and few residual stems. Moderate levels of pine and hardwood competition. Sensitive areas where chemicals and fire are inappropriate. Soils with high bulk density. No serious terrain operability constraints.

Pre-burn, Shear-Disk.--Same as Shear-Disk except: 1) More ground obstructions (especially tops). 2) More vigorous hardwood competition.

Shear, Disk (2-pass).--Moderate levels of residual stems and ground obstructions (too heavy for Shear-Disk, but not enough to impede disk penetration). Fire restrictions. Where preservation of organic matter is essential. Moderate hardwood competition.

Chop, Disk (2-Pass).--Same as above except: 1) Chopping may offer superior control on small pine seeelings or saplings. 2) Chopper may break up lighter debris, facilitating better disk penetration.

Shear, Burn, Disk (2-Pass).-- High levels of residual stems and debris. Vigorous hardwood competition. High soil bulk density. Absence of steep slopes or erodable soils. Fertile soils where hardwood competition is likely to be vigorous.

Chop, Burn, Disk.--Same as above except: 1) Chopping will more effectively break up residual material. 2) Chopping also improves fuel conditions for burning, and enhances burning flexibility.

Chop, Burn, Disk.--Same as above except: 1) Chopping will more effectively break up residual material. 2) Chopping also improves fuel conditions for burning, and enhances burning flexibility.

Shear, Rake.--Sandy soils where bulk densities are low. Minimal hardwood competition. Extremely high residual levels. Fertile soils. Fire restrictions (windrows could be left unburned).

Shear, Rake, Disk.--Same as Shear, Rake except: 1) Where hardwood competition is more vigorous. 2) Soils with high bulk densities. 3) Low erosion potential.

Bedding.--Can be substituted for disking in any of the above treatments where excessive soil moisture can cause seedling mortality.

Subsoiling.--Can be added to above treatments on soils with hardpans.

Notes:

--- "Vigorous hardwood competition" refers to species component as well a number of stems.

--- In two-pass treatments involving disking, the tractor can be equipped with either a KG blade or V-blade during the harrowing pass to clear debris and facilitate disk penetration.

--- Exercise caution in prescribing Shear-Disk (1-Pass) treatment where heavy debris remains following harvest. Disk penetration will be limited resulting in poor hardwood control.

--- All disking should be done between June 1 and October 30, if possible, to maximize hardwood control and minimize damage associated with soil disturbance during wet conditions.

Pine Regeneration

Moderator:

John F. Hosner

Virginia Polytechnic Institute and State University

SURVIVAL AND EARLY GROWTH OF LOBLOLLY PINE SEEDLINGS FROM SIX NURSERIES [1]

Harry S. Larsen, David B. South, Hans M. Williams and James N. Boyer [2]

Abstract. -- Root growth potential (RGP) and bud activity, were positively correlated with first-year survival of loblolly pine seedlings. Poor field performance resulted when seedling samples contained a high proportion of dormant buds (buds that did not break after three weeks of greenhouse conditions). Seedling growth was positively correlated with average seedling diameter and with nitrogen concentrations in the foliage, stems and roots. Results from this study were very similar to that reported for a 20 nursery comparison.

INTRODUCTION

There have been several studies that compare the outplanting performance of southern pine seedlings from different nurseries. In general, the studies find that, for a given year, seedlings from some nurseries perform better than seedlings from other nurseries. The objective of these studies is to determine those seedling attributes that are consistently related to field performance.

In 1982, the Auburn University Southern Forest Nursery Cooperative established such a study (Larsen and others 1986; 1988). Seedlings samples were obtained from 20 nurseries located throughout 6 southern states. Seed sources varied among the samples but all originated from Livingston Parish, Louisiana. During the third week of December a subsample from each nursery was outplanted on a dry site near Shorter, AL. Other subsamples were used for mineral analysis, morphological measurements, and to test root growth potential (RGP) and bud break.

After three years, there were rather large differences among samples in survival and growth. Survival was positively correlated with rate of bud-break and RGP, and negatively correlated with shoot/root ratio. Growth was positively correlated with N content of the foliage. The results suggested that a good part of the variation in field performance among samples could be due to differences in environment to which the seedlings were exposed in the nursery.

However, since the seed source was not uniform, the possibility of the differences being related to a genetic influence could not be ruled out. In addition, there was variation in sowing date, sowing density, and lifting date. Length of time in cold storage also varied (though all samples were stored less for 2 weeks or less). Although all seedlings were sorted according to Wakeley's grades, individual seedling diameters were not measured.

In 1984, a similar nursery comparison study was established. This time, seedling diameters were measured and seed source was kept the same for all nurseries. The objective of this study was to determine if the correlations found in the 1982 study would be repeatable.

PROCEDURE

In the spring of 1984, single plots (1.2 by 1.8 m) were hand-sown at 7 of the 20 nurseries from the 1982 study. Nurseries included in the study were selected on the basis of their survival performance in the 20 nursery study. Two nurseries (1 and 8) exhibited high survival, two had moderate survival (6 and 5), while three nurseries (18, 19, and 20) had low survival. Seed sown were obtained from a Weyerhaeuser seed orchard (from clone 8-74). Sowing density at each nursery was 333 seed/m^2. All plots were mulched with pine bark. Subsequent cultural practices varied by nursery.

At six nurseries, seedlings were hand-lifted after undercutting in December. At nursery #20, seedlings were lifted without undercutting and under less than optimal soil conditions. Because the fine-textured soil was dry, many laterals were broken or stripped during the lifting process. For this reason, results from this nursery have been deleted.

After lifting, seedlings were packed in ice and transported to cold storage at Auburn. Soil samples were taken from each plot for textural and mineral analysis. Each seedling sample was later briefly removed from cold storage, separated into grades according to Wakeley (1954), and random samples of the plantable seedlings were selected for outplanting. Additional samples were taken, to test RGP, bud break, and for morphological measurements and mineral analysis.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Associate Professors and Graduate Research Assistant, Auburn University Southern Forest Nursery Management Cooperative, School of Forestry, Auburn University, AL 36849-5418; and Post-doctorate, Clemson University, Forestry Sciences Laboratory, Charleston, SC 29414.

The taproot of all seedlings was pruned to 18 cm. A fifteen-seedling subsample from each plot was separated into leaves, stems and roots, and these were analyzed for content of all macro- and micro-elements.

RGP was tested using 28 grade 2 seedlings with set buds. Seedlings were potted in sand and kept on a greenhouse rooting bed for 4 weeks with the rooting medium maintained at about 25°C (Larsen and Boyer 1986). Bud activity was recorded after 20 days. After 28 days, the number of new roots ($\geq$ 0.5 cm), the weight of new roots were recorded.

Outplantings were made on January 7 and 8, 1985. The outplanting site was located near the 1982 study at the Alabama Agricultural Experiment Station at Shorter, Alabama. The site includes soils of the Blanton and Norfolk series which have loamy sand topsoils and an estimated loblolly pine site index (base age 50) of 24 meters. The topsoil has an average sand content of 81 percent. Ten to fifteen percent of the soil volume contains gravel.

The outplanting was a randomized block with 8 replications and 16 seedlings per plot. Each planted subsample contained both grade 1 and grade 2 seedlings, in the same ratio as in the complete sample. Seedling heights and groundline diameters were measured after planting and in the fall of 1985, 1986 and 1987. Heights were also measured in July of 1985.

Correlation analyses were used to examine the relationship between field performance and the RGP variables, seedling morphology, and mineral nutrition. All correlations contain 6 observations.

RESULTS AND DISCUSSION

Seedling production

Five of the nurseries were sown during the period between 19 and 23 of April. Due to a combination of fine soil texture and low spring rainfall, sowing at nursery C was delayed one month (table 1). This delay in sowing not only increased seedling mortality, but also resulted in the highest percentage of culls (28%).

With the exception of nursery sample 8, there is not a wide variation in final seedbed density. However, there was a wide variation in seedling grade yields with about a five-fold difference in the production of grade 1 seedlings. Differences in fertilization, irrigation, and undercutting can affect the production of grade 1 seedlings.

Table 1.--Seedling production by grade at each nursery, with sowing and lifting dates

Nursery code[1/]	Date sown	Date lifted	Seeding grade 1	2	Cull	Total
			----------	#/M^2	----------	
1	4/19	12/27	24	210	48	282
5	4/23	12/27	16	220	79	315
6	4/19	12/27	16	198	53	267
8	5/17	12/28	18	125	57	200
18	4/23	12/27	48	197	70	315
19	4/20	12/28	86	120	41	247

[1/] Nursery codes are the same as those reported by Larsen and others (1988).

Seedling survival

Average survival was about 37 percentage points lower for the 1984 study than for the 1982 study. The differences in survival could be related to differences in depth of topsoil and/or unusually cold weather which occurred soon after planting.

Although the two planting sites are close to one another (within 50 meters), the coarse textured topsoil is about twice as deep (60 cm) on the 1984 planting as on the 1982 study (30 cm). Both areas have a silty clay loam subsoil. This may explain why most (all but 6 percentage points) of the mortality in the 1982 study occurred during the first six months after planting while in the 1984 study, survival declined an additional 23 percentage points after June, 1985. Thus, low soil moisture may have been more important and more persistent during the 1984 study.

Weather records from a station maintained less than 1 kilometer from the planting site revealed that unusually low temperatures occurred soon after planting. Beginning one week after planting daily minimums fell to -7°C or below on eight nights during a two week period. On two successive nights, the low temperature reached -18°C and -19°C. In February, 1985, it was observed that about 1/3 to 1/2 of each seedling's foliage was dead. Therefore, seedlings in this study were subjected to much more injury from freezing than seedlings from the 1982 study. This could also help to explain why seedling survival was much lower than in the 1982 study.

Except for nursery #19, the order of seedling survival was similar for both the 1982 and 1984 studies. Nurseries #1 and #8 ranked near the top in both years and nursery #18 ranked last in both years (table 2). The fact that nursery #19 increased in ranking from near last in 1982 to first in 1984 suggests that changes in management practices can result in dramatic improvements in seedling survival. Improved performance likely resulted in producing better balanced seedlings that were 2.8 times heavier and had 4.8 times more root weight than seedlings produced in 1982.

ble 2.--Seedling survival by nursery for the 1982 study and the 1984 study

rsery	1982		1984	
	- % -	rank	- % -	rank
	56	12th	56	1st
	85	2nd	52	2nd
	86	1st	51	3rd
	74	8th	42	4th
	75	7th	34	5th
	55	14th	29	6th

In the 1982 study, RGP was positively rrelated with survival (Larsen and others 86). Similar r values were obtained in the 84 study (table 3). The correlation between root weight and survival was the same for th years (r = 0.80). The three nurseries with P values above 68 new roots (or 80 mg of new ots) had 51 to 56 percent survival. The maining nurseries had survival rates below 45 rcent (table 4). In the 1984 study, there was strong correlation between new root weight and d activity (r= 0.94).

Bud activity in the greenhouse was positively rrelated with survival in the both the 1982 udy (r= 0.60) and 1984 study (r= 0.84). For e 1984 study, the three nurseries with the eatest bud activity (>30% active buds after 28 ys in the greenhouse) exhibited above 50% rvival while the nursery with the poorest rvival had seedlings with very dormant buds (no d activity after 20 days). We believe that thholding irrigation during the fall at rsery #18 resulted in an extended period of edling stress which caused the seedlings to ter a deeper state of bud dormancy.

ble 3. --Correlation coefficients of various seedling attributes with third-year survival and volume (n = 6)

edling attribute	Survival	Volume
	------ r value[1] ----	
ght of new roots	0.80	0.92
mber of new roots	0.70	0.64
mber of active buds	0.84	0.92
ot collar diameter	0.64	0.89
iage weight	-0.09	0.19
iginal root weight	0.42	0.79
ot volume	0.40	0.79
oot/root ratio	-0.37	-0.73
em length/stem weight	-0.68	-0.95
em weight	0.17	-0.18
em length	-0.34	-0.73
liar N	0.56	0.68
liar S	-0.75	-0.86
liar Fe	0.42	0.72
em N	0.62	0.75
em P	-0.78	-0.80
em Fe	0.20	0.84
ot N	0.65	0.84
ot P	-0.88	-0.94

Correlations $\geq$ 0.72, 0.81 and 0.92 are significant at the 0.10, 0.05 and 0.01 levels of probability, respectively.

Although the shoot/root ratio was an important morphological trait in 1982 study (r = 0.76), the correlation was not significant in the 1984 study. The low correlation was due to sample #6 which had the best shoot/root ratio but also had the lowest RGP and poor survival. By deleting sample #6, the correlation between survival and the shoot/root ratio becomes significant (r= -0.92; P>r = 0.025; n= 5). For sample #6, what appears to be a good shoot/root ratio is due to a lack of foliage instead of a good root system (table 4). Since RGP is dependent upon current photosynthesis, a lack of foliage could result in low RGP. This indicates that even with a good shoot/root ratio, survival can be poor when RGP is inadequate.

It is sometimes suggested that seedlings with higher foliar nitrogen concentrations may be more susceptible to injury from freezes than seedlings with lower concentrations of nitrogen. Even though seedlings were subjected to hard freezes soon after planting, seedlings with higher foliar nitrogen concentrations (>1.8%) actually exhibited higher survival than seedlings with lower N concentrations. Since this relationship was not statistically significant (table 3) the results support previous findings (Larsen and others 1986) that indicate that for loblolly pine, there is not a strong relationship between survival and foliar nitrogen concentration.

Volume production

Mean third-year tree volumes (D^2H) are listed by sample in table 3. Analysis of variance showed a significant difference among samples (P>F= 0.03). Average volume for the best sample was 93% greater than that of the poorest sample. After three years, mean volume per plot was 375 percent of that for the poorest sample.

Initial seedling diameter was well correlated with third-year tree volume (table 4). This is not surprising since a number of studies with southern pines have shown that seedlings with larger diameters grow more than seedlings with smaller diameters. Unlike other traits, seedling diameter can be quickly measured, is non-destructive, and can be measured on individual seedlings prior to planting.

For both studies, three-year height growth was correlated with foliar nitrogen concentration. For the 1984 study, both height (r= 0.80) and diameter growth (r= 0.80; P>r <0.06) were correlated with foliar N concentration. In addition, three-year volume was significantly correlated with both stem N concentration and root N concentration (table 4). Although, in the 1982 study, foliar N content exhibited higher r values than foliar N concentrations (Larsen and others 1988), the reverse was true for the 1984 study. Thus far, we can provide no biological explanation for the negative correlations of seedling growth with S and P concentrations.

Table 4.--Mean seedling RGP, bud activity, morphological measurements and mineral concentrations for each greenhouse sample along third-year survival and total volume

Seedling Characteristics	Nursery sample					
	19	1	8	5	6	18
GREENHOUSE PERFORMANCE						
Weight of new roots (g)	0.13	0.09	0.14	0.05	0.07	0.04
Number of new roots	112.1	74.2	69.1	59.0	45.7	67.4
Active buds (%)	89	32	75	14	21	0
SEEDLING MORPHOLOGY						
Root collar diameter (mm)	4.3	4.0	4.2	3.7	4.0	3.9
Foliage weight (g)	1.21	0.96	1.25	1.10	0.87	1.42
Original root weight (g)	1.59	1.26	0.77	0.54	0.75	0.59
Shoot/root ratio	2.61	2.96	2.56	3.60	2.17	3.87
Stem length (cm)	20.8	21.5	17.7	27.9	20.0	23.8
Stem length/stem weight	27.5	29.1	27.2	35.5	30.2	33.8
SEEDLING NUTRITION						
Foliar N (mg)	22.3	18.0	26.5	15.4	13.4	24.6
Foliar N (%)	1.85	1.87	2.12	1.40	1.55	1.73
Foliar S (%)	0.06	0.06	0.05	0.09	0.06	0.08
Foliar Fe (ppm)	338	464	401	122	494	68
Stem N (%)	1.01	0.91	1.15	0.53	0.67	0.81
Stem P (%)	0.10	0.14	0.15	0.15	0.15	0.17
Stem Fe (ppm)	177	308	196	86	319	89
Root N (%)	0.95	0.92	0.79	0.56	0.73	0.72
Root P (%)	0.11	0.17	0.12	0.20	0.19	0.24
FIELD PERFORMANCE						
Third-year survival (%)	56a[1]	52a	51ab	42ab	34ab	29b
Third-year volume (cc)	1524a	1298ab	1360ab	852b	1108ab	788b

[1] Values not followed by the same letter differ significantly at the 0.05 level.

The variable most strongly correlated with growth was stem length/stem weight ratio. Samples with low stem length/stem weight ratios may have contained a higher percentage of stored carbohydrates in the stem (indicated by a higher stem specific gravity).

CONCLUSIONS

Results from the 6 nursery comparison are in general agreement with earlier findings from the 20 nursery comparison study. In both studies, seedling survival was positively correlated with RGP and bud activity. Although the nitrogen status was not related to survival, early growth of seedlings was positively related to nitrogen status of the seedlings at lifting.

Volume growth was positively related to initial seedling diameter. In addition, seedling samples that were slow to break bud in the greenhouse also grew less in the field. This supports a previous conclusions that seedlings with a high proportion of dormant buds should not be planted on sites where survival may be a problem (Larsen and others 1986).

Since the same seed lot was used at all six nurseries, the large differences in field performance are attributable primarily to differences in nursery environment. The study confirms that the effects of nursery management practices can persist for at least several years after planting.

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SITE PREPARATION, CONTAINERS, AND SOIL TYPES AFFECT FIELD PERFORMANCE OF LOBLOLLY AND LONGLEAF PINE SEEDLINGS[1/]

James P. Barnett 2/

Abstract.--Field performance of container-grown pine (*Pinus* sp.) seedlings is affected by the type of container, the degree of site preparation prior to outplanting, and the quality of the site. Growing fewer container seedlings per unit area usually produces larger, better quality stock that performs well in the field. The ability of the root systems of container seedlings to become quickly established is particularly important on droughty or stressed planting sites. Need for extensive site preparation is important for longleaf pine (*P. palustris* Mill.) establishment, this species clearly is extremely sensitive to competition, especially on adverse sites.

INTRODUCTION

Considerable evidence has been collected on the erformance of container-grown loblolly (*Pinus aeda* L.) and longleaf pine (*P. palustris* Mill.) eedlings on typical reforestation sites (Barnett nd Brissette 1986). Container stock performs etter than bare-root stock when planted on dverse sites (Amidon and others 1982; South and arnett 1986; Boyer 1985). Some evidence suggests he amount and type of site preparation necessary or successful establishment may differ between ontainer and bare-root seedlings (Ruehle and thers 1981). Performance of container stock is lso affected by the type of container used.

Increased survival and growth of pines ollowing control of plant competition has been oted (McMinn 1969, Derr and Mann 1970, Campbell nd Mann 1971, Malac and Brightwell 1973). Those esponses are probably due to the increased vailability of soil water (Terry 1981). Coile 1936), Carter and others (1984), and Zahner 1962) recognized the importance of soil water to rowth and noted an increase in water availability ollowing competition control. The herbaceous omponent (grasses, forbs, vines, and semi-woody lants) of pine stands competes vigorously for vailable soil water during seedling establishment. Therefore, failure to reduce both herbaceous and woody competition probably accounts for varied treatment responses in some studies (Haywood and others 1981). The importance of each component has been quantified (Miller and others 1987). Clason (1978), for example, observed that 5 years after control of both hardwood and herbaceous vegetation, volume growth of wood in a 12-year-old loblolly pine stand was improved by 63 percent as compared to 45 percent with only hardwood removal.

The effects of type of container, degree of site preparation, and soil type on the survival and growth of loblolly and longleaf pine seedlings are reported here.

METHODOLOGY

Eighteen treatment combinations (3 containers, 2 soil types, and 3 site preparation treatments) were evaluated by planting four replications of 25-seedling plots. The container materials evaluated were Japanese Paperpots® (tubes), Styroblock-4's® (plugs), and Keyes Tree-Starts® (blocks). Loblolly and longleaf pine seedlings were grown from locally collected seed sources for about 14 weeks in a greenhouse in these materials and then outplanted on Beauregard silt loam and Ruston sandy loam soils that had received one of three site preparation treatments. The site preparation variables were (1) burning, (2) scalping the planting row with a fire plow, and (3) single disking of 6-foot-wide strips. The treatments were applied to areas that had been clearcut of all trees and that supported a heavy grass rough.

A peat-vermiculite (1:1) potting medium was

[1/] Paper presented at Fifth Biennial Southern ilvicultural Research Conference, Memphis, TN, ovember 1-3, 1988.

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used to fill the Paperpots and Styroblocks, and all seedlings received fertilization (20-19-18 NPK) through the watering system twice weekly during the last 10 weeks of the 14-week growing period. The seedlings were characterized at the time of outplanting by determining heights (loblolly pine only), stem diameters, and root and shoot dry weights of five seedlings per treatment replication. Survival and heights (for loblolly pine) or root-collar diameters (for longleaf pine), were measured in the dormant season following planting and again 1 and 2 years later.

A split-plot design was used in the study with soil types as main plots and containers and site preparation as minor plots. The 0.05 level was used to test statistical significance.

RESULTS AND DISCUSSION

Seedling Development

Container type influenced initial seedling development. Stem diameters and dry weights of longleaf pine were smallest in Paperpot containers, and increased in Styroblock and Tree-Start containers (table 1). These differences are at least partially due to the space available for development--numbers per square foot are 154, 73, and 123 for the tube-, plug-, and block-type containers. However, the Tree-Starts also have nutrients incorporated in the block that improve seedling development. There were no statistically significant differences between Paperpot and Styroblock containers in development of root systems.

Although loblolly pine seedling heights were not significantly increased by container type, diameters and dry weights of both stems and roots increased progressively with Paperpots, Styroblocks, and Tree-Starts (table 1). These differences reflect the number of seedlings per unit area and incorporation of nutrients into the manufacture of Keyes' Tree-Starts. Variation in field performance related to container types is due to differences in seeding size.

Table 1.--Characteristics of loblolly and longleaf pine seedlings at time of planting

Seedling characteristics	Loblolly pine: Paperpot	Loblolly pine: Styro-4	Loblolly pine: Tree-Start[2]	Longleaf pine[1]: Paperpot	Longleaf pine[1]: Styro-4	Longleaf pine[1]: Tree-Start[2]
Height (mm)	227	212	228	—	—	—
Diameter (mm)	2.2	2.3	2.5	2.2	3.0	3.3
Top wt.(mg)	730	834	1053	576	674	1074
Root wt.(mg)	138	243	—	131	127	—

[1] Seedling heights of longleaf pine could not be measured.

[2] Roots could not be recovered from Tree-Starts.

Seedling survival

Loblolly pine.--Seedling survival at 2 1/2 years after outplanting varied by type of container, soil type, and site preparation treatments, and there were statistically significant interactions among these variables. Regardless of containers, average survival was better on the sandy-loam soils, especially for seedlings planted on burned and disked sites (fig. 1). However, seedlings planted on scalped sites performed equally well on both soils. Generally, the Paperpot-grown seedlings had lower survival on sandy-loam soils than the other container types, but this distinction did not occur on silt-loam soils where site preparation was burning or scalping.

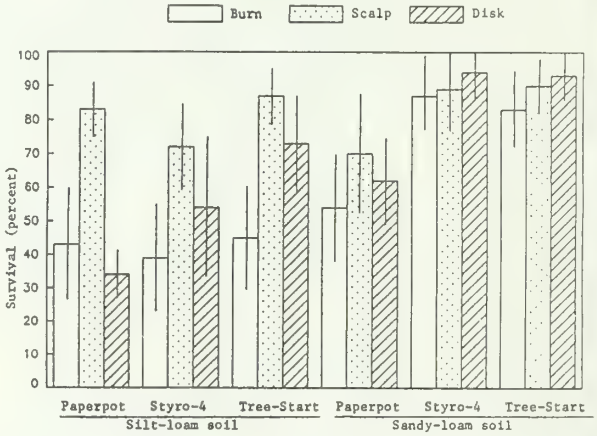

Figure 1.--Survival of loblolly pine seedlings 2 1/2 years after planting. Line in each column is the standard deviation of plot means.

After 2 1/2 years, competing vegetation was greatest on burned plots, less on disked plots, and still less where scalping was done. However, scalping treatments have the potential to reduce the long-term productive capacity of infertile soils (Brendemuehl 1967).

Longleaf pine.--Survival after 2 1/2 years was generally lower for longleaf than loblolly pine. The magnitude of differences due to containers and site preparation treatments was also greater, but again there were statistical interactions among treatments. On silt-loam soils survival rates of seedlings in Paperpots and Tree-Starts were low, averaging about 20 and 5 percent, respectively, and increased with the use of Styroblock containers (fig. 2). The scalping treatment produced higher survival than burning or disking on the silt-loam soil condition. A similar pattern did not occur on the sandy-loam soils. The Styroblock seedlings performed best on this site, and scalping or disking treatment was better than burning as a site preparation treatment.

These data indicate that longleaf pine survival is more sensitive than loblolly to variations in herbaceous competition that develops following different site preparation treatments. Seedling development due to container type markedly influences field survival. The larger initial seedling sizes resulted in better survival.

Why survival patterns due to container and site preparation treatments varied by soil type was not evident. Scalping was the best preparation treatment on silt-loam soils, but disking was better on the sandy soils, especially with longleaf pine.

Seedlings grown in Styroblocks generally survived better than Paperpots or Tree-Starts. This is probably due to poor early root egress into the soil after outplanting. The paper tubes, particularly, limit early root contact with the soil.

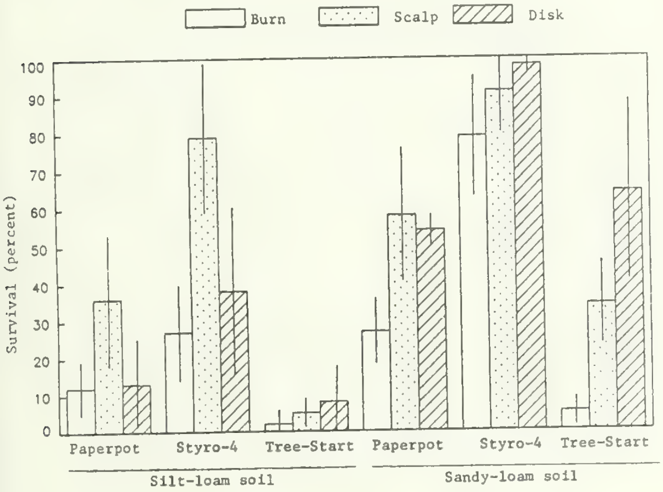

Figure 2.--Survival of longleaf pine seedlings 2 1/2 years after planting. Line in each column is the standard deviation of plot means.

Seedling growth

Loblolly pine.--All treatment variables had less effect on seedling heights than on survival. Loblolly pine seedlings grown in Tree-Starts had the best field growth response (fig. 3). These seedlings averaged nearly 1-foot taller than those grown in either Paperpots or Styroblocks, particularly on the sandy-loam soils. The stock planted on disked sites outperformed that planted on burned or scalped sites; and, again, the greatest differences occurred on sandy-loam soils.

Longleaf pine.--Root-collar diameters of longleaf pine were affected variously by the types of treatments. Overall stem diameter growth was greater on disked than on burned or scalped sites, particularly when seedlings were grown in Paperpots or Styroblocks (fig. 4). This probably reflects less competition due to more intensive site preparation. Seedlings in Tree-Starts had the greatest diameters, probably reflecting the initial larger size of this stock when planted.

CONCLUSIONS

Field performance of container stock is affected by the type of container, the site preparation provided, and by site quality. Containers providing lower seedling densities usually produce larger and better quality stock. Root systems that establish quickly in soil improve initial seedling survival, particularly on droughty sites.

Longleaf pine seedlings are very sensitive to competition and overall performance is markedly improved by those techniques that reduce herbaceous plant competition. Both seedling survival and growth respond markedly to such treatments.

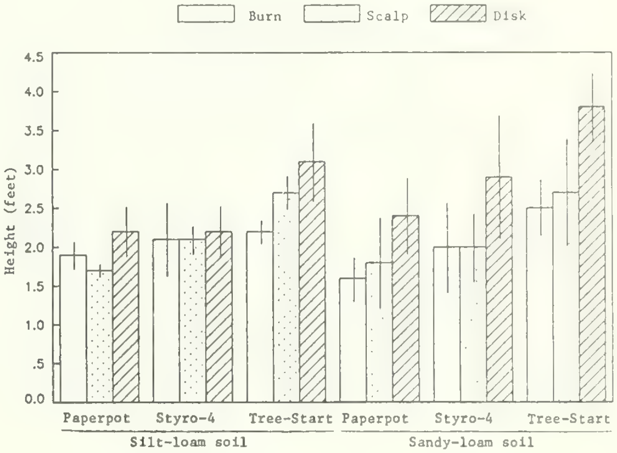

Figure 3.--Heights of loblolly pine seedlings 2 1/2 years after planting. Line in each column is the standard deviation of plot means.

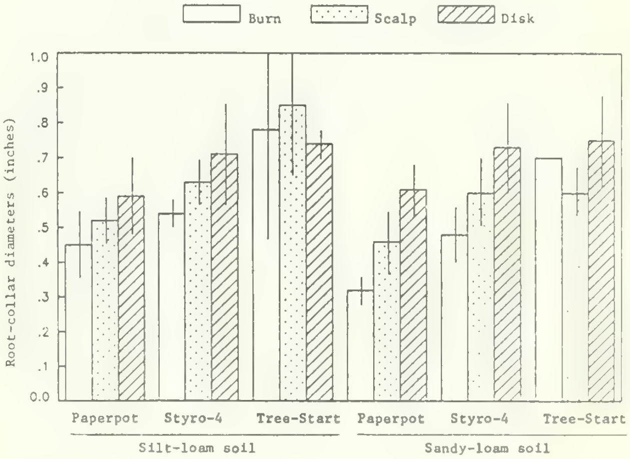

Figure 4.--Root-collar diameters 2 1/2 years after planting. Line in each column is the standard deviation of the plot means.

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RESPONSE OF LONGLEAF PINE TO VARYING INTENSITY OF SILVICULTURAL TREATMENTS[1]

Robert W. Loveless, John A. Pait, III and Tim McElwain[2]

Abstract.--In 1983 a study was initiated in Santa Rosa County Florida, to examine the effects of intensive cultural treatments upon the survival, emergence from the grass stage and the growth of longleaf pine. Treatments in a split plot design included a factorial combination of upland bedding, fertilization and competition control. Survival was affected by the site preparation treatment. Emergence from the grass stage during the first two years after planting increased directly with the intensity of the cultural treatments. At age four, mean pine height differed among the treatments with the greatest total height correlated with increasing intensity of treatments. The total margin between the most intensively treated sites versus the control plots was 7.4 feet. Treatment effects on height appear to be additive rather than synergistic. Mean height of the pines was more strongly correlated with competition control of the hardwoods and herbaceous species than with any other treatment.

INTRODUCTION

Longleaf pine (Pinus palustris Mill.) has long been considered one of the most valuable of the southern pines. Until the settlement of the United States by European settlers some three hundred years ago, longleaf pine was the primary southern pine species. Its natural range (fig. 1) placed it in the lower and middle coastal plain section of the southeast United States running from southeastern Virginia to Louisiana, crossing the Mississippi River and growing into eastern Texas. It is estimated that during this period of the 17th century, some 60 million acres were predominantly occupied by this species (Dennington and Farrar 1983). Today, that range has shrunk from approximately 15 million acres reported in 1975 (Croaker and Boyer 1975) to 5 million acres in 1983 (Dennington and Farrar 1983).

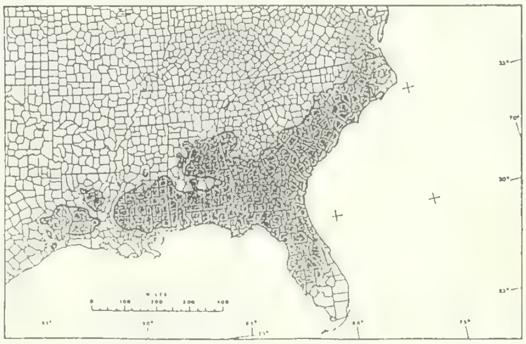

Figure 1.--The botanical range of longleaf pine[3].

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[1] Paper presented at the Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Research Supervisor, Container Corporation of America, Brewton, Alabama; Research Supervisor, Container Corporation of America, Callahan, Florida; Research and Development Manager, Container Corporation of America, Brewton, Alabama.

[3] Silvics of Forest Trees of the United States, Agriculture Handbook No. 271, USDA Forest Service.

Ecologically, the reduction of longleaf pine's range is due to the fact that this species filled a niche that is no longer found throughout large parts of the southeastern United States. Longleaf pine is known as a fire sub-climax species. Except for a short period of time immediately after germination and another period of approximately two years after emergence from the grass stage, the species is remarkably tolerant to fire. It is much more tolerant than the other major commercial southern pine species of loblolly pine (*Pinus taeda L.*) and slash pine (*Pinus elliottii Engelm. var. elliottii*). History indicates that both natural and man-made fires set by Indians were extensive and occurred periodically on the southeastern coastal plain. This periodic burning created the conditions favorable to the widespread reproduction of longleaf pine. These favorable conditions included freedom from herbaceous competition during seed drop and germination, followed by freedom from brush and hardwood competition during the establishment phase until height growth was initiated.

The settlement of the United States has changed this environment. First, land was cleared for the production of naval goods and for agriculture. Then cattle and livestock were allowed to roam freely over this forest and grass range. Row crop farming supplanted the trees; and livestock, especially hogs, were detrimental to the reestablishment of seedlings. Most importantly, the control or elimination of fire altered the habitat. Today, open range has largely disappeared from the southeast, and pressure to control or eliminate burning has increased. Fire, instead of being a readily available tool used by foresters, is becoming more difficult to use as population and environmental pressures multiply. Despite these conditions which have altered the natural range of longleaf pine, commercial interest in this species remains. Other pine species have replaced longleaf pine across its natural range, so that today we regard the commercial range as much more site specific. The three primary southern species can be more easily classified by soil site characteristics than by environment. These characteristics are as follows.

Loblolly pine has largely replaced longleaf pine and now occupies the widest range of soils from the lower coastal plain to the Piedmont. It prefers a deep surface layer with a firm subsoil containing clay. The depth to clay should not exceed four feet. Longleaf pine characteristically is tolerant of well to excessively drained sandy loam soils. These soils have low organic matter, are strongly acid and the depth to a clay subsoil, if any, is greater than four feet. Slash pine is usually found on the more poorly drained sandy soils. These may have a hardpan or spodic layer of organic matter some 12 to 48 inches below the surface. These soil drainage characteristics largely determine what species should be planted on the land as related to total fiber production.

Container Corporation has some land characterized by soils and topography that is best suited to longleaf pine. Silviculturally, longleaf pine is a very intolerant species that does not establish well in the presence of brush or grass competition. Natural stands of longleaf pine traditionally take from 4 to 5 years (Croaker and Boyer 1975) to emerge from the grass stage. However, this emergence period may range from 1 to 20 years. Economically, the benefits of intensive site preparation to optimize rapid regeneration may offset the cost involved. This capitalized cost may also be offset by a shortening of the traditionally longer rotation for longleaf pine than is used for the other southern pines.

OBJECTIVES

The objectives of this study are:

1) Examine the effects of different intensities of mechanical site preparation on enhancing the planting survival, the rate of emergence from the grass stage, and the long term growth rate of longleaf pine.

2) Examine the effects of different intensities of silvicultural management activities on enhancing the planting survival, the rate of emergence from the grass stage, and the long term growth rate of longleaf pine.

METHODS

The study is located in Santa Rosa County, in the panhandle of Florida about 30 miles north of Milton. This is a lower coastal plain site which is classified as well drained. The soil survey of Santa Rosa County (Weeks et al 1980) identifies the soils as Fuquay and Dothan. These well drained soils formed in sandy and loamy marine sediments of the Coastal Plain. They are found on ridgetops and hillsides in the uplands. Slopes range from 0 to 12 percent. The A horizon may be from 20 to 40 inches thick. The B horizon will typically be sandy loam or sandy clay loam somewhere between 4 to 5 feet below the surface. There are iron oxide concretions ranging from 0 to 5 percent by volume throughout the soil.

Soil samples were taken before site preparation had disturbed the site and were analyzed by the North Carolina State Department of Agriculture Testing lab. Soil extractions (table 1) were accomplished using the Mehlich III procedure (Mehlich 1978).

Table 1.--Soil extractions from samples taken prior to site preparation

Depth	OM	pH	P	K	Ca	Mg	Mn
Inches	%		-------lbs./Acre---------				
0 - 4	.9	4.9	3	40	223	41	36
4 - 8	.8	4.9	3	37	194	40	36

These indicate relatively low organic matter which is typical of these rather acid soils. Phosphorus levels are also low.

The design of this study was patterned after the North Carolina State Forest Nutrition Cooperative's Region Wide 7 study.[4] It is a split plot design with site preparation as the main treatment. Fertilizer and weed control treatments were allocated to subplots in a factorial arrangement.

Treatments

Main Plots S 0 - Minimum site preparation
S 1 - Intensive site preparation

Subplots F0 W0 - No fertilizer and no weed control
F1 W0 - Fertilizer and no weed control
F0 W1 - No fertilizer and weed control
F1 W1 - Fertilizer and weed control

The plots were identified by a three digit code for site preparation, 0 or 1; fertilizer, 0 or 1; and weed control, 0 or 1.

The four subplot treatments are repeated on each site preparation treatment or main plot, totaling eight plots per replication. After harvest a relatively uniform block in terms of slope and aspect was chosen. Four replications were installed with shearing and raking as the primary site preparation treatment. This was done in the summer of 1983. Each treatment plot is 140 feet wide with rows on a 10 foot spacing, and 132 feet long for a total of .42 acres/plot. The measurement plot consists of the interior 6 rows which are 66 feet long. This leaves a 40 foot buffer strip on each side and a 33 foot buffer at each end. The intensive mechanical site preparation treatment involved double bedding on the previously sheared and raked site in October of the same year.

Machine planting was done in December 1983 on an operational basis. The spacing was approximately 6 feet in the rows. By March 1984, it appeared that survival would not be adequate. To insure enough survival for the study, extra seedlings were hand planted so that spacing was 3 feet within the row. Seedlings were nursery run fom CCA's Rock Creek Nursery. The seed souce was a seed production area in Baldwin County, Alabama.

Nitrogen and phosphorus were applied in May 1984 in the form of diammonium phosphate (DAP). The applied rate was 250 pounds per acre. Fertilizer was distributed with hand spreaders in a 4 to 6-foot band over the rows.

Total control of the brush and herbaceous competition was the objective for two growing seasons after planting. Residual hardwoods were first treated with triclopyr (Garlon) before bedding on the herbicide plots. Garlon was broadcast sprayed in September of 1983. After planting, sulfometuronmethyl (Oust) was applied in April of 1984. Glyphosate (Roundup) was later used to spot treat patches of Johnsongrass. Another treatment of Sulfometuronmethyl and hexazinone (Velpar) was applied in July 1984. In the second year after planting, the herbicide plots were still very clean. A spring application of sulfometuronmethyl was made in 1985.

MEASUREMENTS

The first recorded survival tally was taken in December 1984. Brown spot disease and the number of seedlings out of the grass stage were tallied at this time. Emergence from the grass stage was considered to be accomplished when a definite bud had been formed which would elongate in the next growing season or when elongation had already occurred. A second tally, which was identical to the first, was taken in December 1985. In March 1988, at the end of the fourth growing season, total height was measured.

ANALYSIS

For the first two years, plot survival and the percentage of seedlings emerging from the grass stage were calculated. In the fourth year the plot mean heights were calculated. These summary results are shown in table 2. The plot data were put through analysis of variance at the .05 level of significance.

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[4] NCSFNC Region Wide Study No. 7 Workplan, Loblolly Pine Productivity Study, unpublished.

Table 2.--First and second year survival and emergence percentages and fourth year height by treatment

Site Prep	Fert.	Weed Control	First Year Surv.	First Year Emerg.	Second Year Surv.	Second Year Emerg.	Fourth Year Height
			------------percent			------------	ft
Minimum	no	no	59	2	56	17	1.4
Intense	no	no	47	7	41	41	3.0
Minimum	yes	no	68	3	63	21	2.4
Intense	yes	no	44	12	42	43	4.6
Minimum	no	yes	62	10	58	66	5.2
Intense	no	yes	54	23	50	90	6.2
Minimum	yes	yes	55	22	48	65	7.4
Intense	yes	yes	55	30	51	96	8.8
Average all treatments			56	13	51	55	4.9

RESULTS

Survival percentages and the percent of seedlings that had emerged from the grass stage in years one and two were converted by an arcsine transformation to approximate a normal distribution before analysis of variance was run. Analysis of variance results for survival, emergence and height growth are shown in table 3.

Table 3.--Analysis of variance of treatment effects and interactions on first year survival, first and second year emergence and fourth year height growth 1/

Source	D.F.	1st year survival	1st year emergence	2nd tear emergence	4th year height
Rep	3	.4156	.3250	.0998**	.8175
Site Prep (SP)	1	.0230*	.1134	.0051*	.0413*
Rep x SP (error A)	3	.7757	.2691	.7283	.0291*
Fertilizer (F)	1	.9865	.2086	.4183	.0299*
Herbicide (H)	1	.9498	.0924**	.0493*	.0095*
F x H	1	.6342	.4363	.5987	.0776**
SP x F	1	.7929	.9673	.6282	.2278
SP x H	1	.4216	.5841	.2783	.4433
SP x F x H (error B)	1	.2144	.5083	.4810	.7797

1/

* Denotes significance at probability > F = .05.
** Denotes significance at probability > F = .10.

Analysis of variance showed a significant difference between the basic shear and rake site preparation treatment and the intensive preparation treatment which included bedding. Survival averaged 11 percent better on the unbedded land. There were no other noticeable effects from any of the treatments on the survival rate.

In analyzing the emergence rates in the first year, weed control was the only effective treatment and then only at the ten percent level of probability. By the second year, significance of the weed control treatment had increased to the five percent level. The bedding treatment was also significant in promoting emergence by the second year. After two years, the competition control plots had nearly 50 percent more trees out of the grass stage (fig. 2) than did the plots which did not receive herbicide treatment. The bedding treatment contributed nearly 25% over the control plots to the emergence during the two year period. Fertilizer had a negative effect on emergence during the second year after planting.

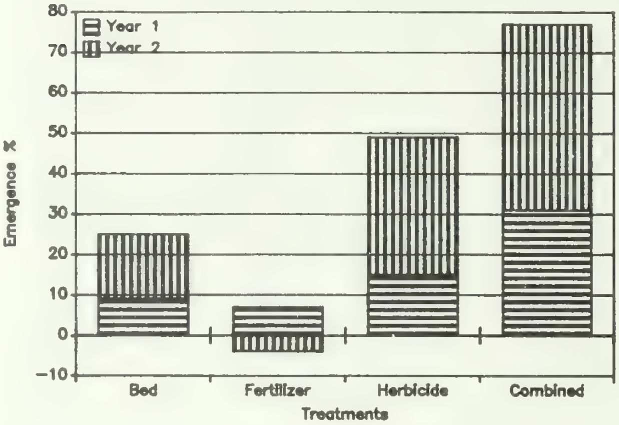

Figure 2.--Marginal rates of emergence between treatments and control.

Analysis of variance showed that each individual treatment was significant in increasing the height growth over the control treatment of minimum site preparation. Each of these treatment effects was additive; however, there was no significant interaction between the treatments of bedding, fertilization and weed control. The single most effective treatment in promoting height growth was the herbicide treatment (fig. 3). These plots averaged four feet in height growth greater than the control plots. Bedding contributed approximately 1.5 feet in height growth while the fertilization added an additional 1.75 feet.

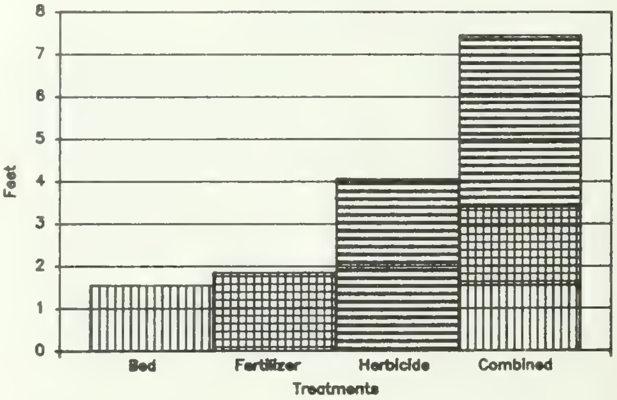

Figure 3.--Marginal height differences between treatments and control. Treatment effects were additive.

DISCUSSION

It is difficult to determine an exact cause for the decline in survival on the bedded areas. One explanation is that the beds were formed in October and might not have had adequate time to settle before planting in December. However, local rainfall records indicate almost fifteen inches of rain between the bedding operation and the time of planting. Another more plausible explanation is based upon the fact that soon after planting a hard freeze hit this area. Our records indicate considerable damage to longleaf pine in the beds at our nursery which is nearby. Perhaps the bedded area at this site froze which caused damage to the seedlings.

There are slight indications that the fertilizer (fig. 2) helped some of the seedlings emerge from the grass stage in the first year, however, this was not at a significant level. The data indicate that it did not help in the second year. Although we found no evidence that the fertilizer affected survival there is conflicting evidence in the literature about the effects of fertilization on survival. Bengston (1976) found that fertilization at time of planting generally reduced survival in his study. One possible reason might be the competition effects on the longleaf pine from competing vegetation especially on plots that did not receive herbaceous control.

The presence of bedding was significant (fig. 3) in promoting emergence. This mechanical tillage of the soil is supported by Croaker (1959) and Boyer (1983) who found that a V-blade in front of the planter, lessened weed competition which promoted emergence.

The strongest data in this study show support for herbaceous weed control as a major factor in emergence of these seedlings from the grass stage. This supports the conclusions reported by Nelson et al (1985) that herbicides reduced the period in the grass stage by one year.

Each treatment effect was additive in terms of emergence and height growth. There is no doubt that the intensity of these treatments did contribute substantially to the total heights (fig. 4) recorded at age 4. This increase is probably primarily due to the early emergence from the grass stage. It will be interesting to see if the growth rates are equivalent on the different plots in the future. Although fertilization has not played a large role in the study to date, it can be expected to increase in significance as the trees get older. The extremely low levels of phosphorous (P) found in the soil suggest that this site may respond to the P fertilization. It has not yet been well established what the critical foliar levels of the macronutrients should be for this species. Bengston (1976) has done some foliar analysis and established that potassium (K) concentrations of .25 - .30% are critical. He found longleaf pine less tolerant and less demanding of fertilizer. But his NPK treatment did show a growth response in longleaf pine. Other critical levels for macronutrients have not yet been defined for this species.

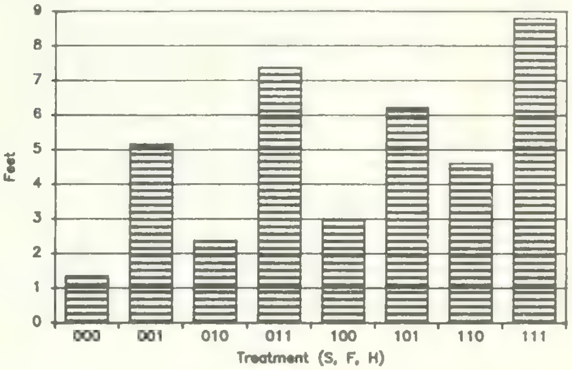

Figure 4.--Average height by treatment at age four.

CONCLUSIONS

Control of competing vegetation either mechanically through bedding or chemically through the use of herbicides seems to be of substantial help in promoting the rapid emergence of longleaf pine from the grass stage. This rapid emergence has led to significant differences in average height of the seedlings through age four. This fact, coupled with longleaf pine's superior adaptability to well drained, sandy loam sites, may result in net present value or internal rate of return conclusions which may enhance the economic desirability of planting this species on appropriate sites.

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RESPONSE OF PLANTED LONGLEAF PINE BARE-ROOT AND CONTAINER STOCK TO SITE PREPARATION AND RELEASE: FIFTH-YEAR RESULTS[1]

William D. Boyer[2]

Abstract.--The effects of several levels of competition control on the development of planted longleaf pine (Pinus palustris Mill.) bare-root and container seedlings was recorded at five locations in Georgia. Two intensities of pre-planting site preparation were each combined with two post-planting release treatments. Five years after planting, survival was better for container (76 percent) than bare-root (51 percent) stock. The height of container seedlings (6.0 ft) significantly exceeded that of bare-root seedings (4.9 ft). Release significantly improved seedling growth and promoted a greater response from container (7.2 vs. 4.7 ft) than from bare-root seedlings (5.5 vs. 4.2 ft).[3]

INTRODUCTION

Longleaf pine has long had a reputation as a slow-growing tree that is extremely difficult to regenerate. Yet, on many former longleaf sites the species, once well-established, can grow as well as, or better than, other pines. Over the years, the longleaf pine type has dwindled from the 60 or more million acres in pioneer times to less than 4 million acres today. The type will continue to decline unless it can be successfully regenerated. If longleaf is to be returned to some of the sites it once occupied, some form of artificial regeneration will be required. Unfortunately, the problem of poor survival and slow early growth has continued to inhibit reestablishment of longleaf on its former lands, even when it has been the species of choice for the site.

Successful planting of longleaf pine requires careful attention to details, beginning in the nursery and continuing through outplanting in the field. After that, field conditions can have a serious impact on seedling survival and growth.

A study was initiated in 1983 to determine the effects of field conditions on the survival and early growth of planted longleaf pine. Plantation establishment was an attempt to simulate a normal, commercial planting operation for both bare-root and container seedlings. The goal was to observe seedling response to field conditions as modified by several competition control treatments.

Establishment details, first-year survival of planted seedlings, and seedling development through 3 years in the field have been reported (Boyer 1985, 1988). This paper covers seedling survival and growth through 5 years.

METHODS AND PROCEDURES

Location

This study was established on five coastal plain sites in Georgia, as follows:

1. Butler (Taylor Co.); sandhills turkey-bluejack oak type.

2. Soperton (Treutlen Co.); sandy middle coastal plain site.

3. Waycross (Ware Co.); lower coastal plain flatwoods site.

4. Valdosta (Lowndes Co.); lower coastal plain flatwoods site.

5. Albany (Dougherty Co.); middle coastal plain site.

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[1] Paper presented at Southern Silvicultural Research Conference, Memphis, Tennessee, November 1-2, 1988.

[2] Principal Silviculturist at the George W. Andrews Forestry Sciences Laboratory, Auburn, AL, maintained by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with Auburn University.

[3] The author wishes to express his appreciation to the Division of Research, Georgia Forestry Commission, for its support and cooperation in the conduct of this study.

Treatments

At each location, except Albany, about 3 acres were set aside for the study, with half of the area being assigned to one preplanting site preparation treatment and half to another. The two intensities of mechanical site preparation treatments, installed in the fall and winter of 1982-83, were:

1. Low. Complete removal of all trees plus one mechanical pass (chop or harrow) for brush control.

2. High. Same treatment as above plus and additional pass with mechanical equipment (chop or harrow).

Each site preparation treatment was split for two post-planting release treatments:

1. Release. Velpar L applied as a spray at the rate of 1 lb a.i. per acre (0.75 lb on Butler sandhills site) in water to make about 30 gal of spray per acre. The herbicide was applied by a crawler tractor with a cluster nozzle. All spraying was done from July 6 to July 8, 1983.

2. No release.

The Albany site had a residual longleaf pine overstory averaging about 20 ft^2 basal area per acre. A hot winter burn was the only site preparation treatment, and this area was split for application of the two release treatments. Although this location was necessarily omitted from the experimental design, regular observations were made here to follow the effects of release.

Planting

Longleaf pine bare-root nursery stock and container stock were planted on all study sites. Planting, done in a normal operational manner, was completed during the period March 1 to March 4, 1983 at four locations and on March 10 at the fifth location. Bare-root seedlings came from the E.A. Hauss Nursery near Atmore, Alabama, and were representative of the seedlings produced by this nursery, which have done very well in the field. Seedlings were lifted February 24, 1983 and transported to the first planting site February 26. Bare-root seedlings were machine-planted with a Whitfield planter pulled by a crawler tractor. Container seedlings were obtained from a Southern Station Research Work Unit of the USDA Forest Service in Pineville, LA. Seedlings were grown in 10 in^3 RL Single Cells and were about 25 weeks old when planted. Seedlings were removed from the plastic tubes in the field, and the plugs hand-planted using a dibble.

Seedlings were planted at a spacing of about 6 by 12 ft (600 trees/acre). In each of the four treatment plots per location (two at Albany), about 500 bare-root and 100 container seedlings were planted. Within each treatment plot, 100 bare-root and 50 container seedlings were marked for observations of survival and growth with a flag pin.

Measurements

The survival of marked seedlings was checked a total of 6 times through the first year after planting, and again at the end of the second, third, and fifth growing seasons. Beginning at end of the second growing season in the field, the numbers of marked seedlings in active height growth (>=0.5 ft in height to base of terminal bud) and their heights (measured to nearest 0.1 ft from groundline to base of terminal bud) were recorded.

Analysis of variance, with significance established at the 0.05 level, was used to determine the effects of treatments on seedling survival and growth in this split-split plot experiment. Bare-root and container seedlings did not come from the same seed source; thus, the possible effects of this factor could not be evaluated.

RESULTS

Seedling Survival

Overall survival of planted longleaf pine seedlings was 63 percent after 5 years in the field. This compares to 65 percent survival at 3 years, 66 percent at 2 years, and 70 percent at 1 year. Most of the total seedling mortality through 5 years occurred during the first year and amounted to about 83 percent of total mortality for both bare-root and container seedlings. Ninety-two percent of total 5-year mortality had occurred by end of the second year. The significant effects of site preparation, release, and seedling type on seedling survival took place almost entirely during the first year in the field. None had any effect after the second year.

Survival at 5 years, in relation to treatment variables, is given in table 1. The survival of container stock (76 percent) was significantly greater than that of bare-root seedlings (50.8 percent). The survival of released seedlings (56.4 percent) remained significantly less than that of unreleased seedlings (70.4 percent) due to herbicide-related mortality during the first year. Seedling survival with the high level of site preparation was still greater (70.7 percent) than with the low (56.1 percent), but the difference was no longer large enough to be significant.

able 1.--Overall survival of planted longleaf pine after 5 years in relation to seedling type, site preparation, and release

eedling type	High site prep.		Low site prep.		
	Release	No release	Release	No release	Average
	percent				
ursery	43.5	64.8	42.5	52.2	50.8
ontainer	84.5	90.0	55.0	74.5	76.0
Average	64.0	77.4	48.8	63.4	63.4

Seedling survival through 5 years, by site eparation and release, is shown in table 2 for ach location. Survival did not differ ignificantly among locations (Albany excluded) espite the range in site conditions. Only on the ow site preparation treatment at Waycross did the urvival of bare-root seedlings exceed that of ontainer seedlings.

able 2.--Survival of longleaf pine 5 years after planting, by treatment, for each study location

ocation	High site prep.		Low site prep.		
	Release	No release	Release	No release	Average
	percent				
	Nursery Stock				
utler	26	55	30	54	41.2
aldosta	47	75	43	36	50.2
aycross	36	58	50	64	52.0
operton	65	71	47	55	59.5
lbany	--	--	36	30	33.0
	Container Stock				
utler	66	72	40	84	65.5
aldosta	82	94	82	82	85.0
aycross	94	98	12	58	65.5
operton	96	96	86	74	88.0
lbany	--	--	84	86	85.0

Seedling Growth

At the end of the third year in the field, 67 percent of all seedlings were in active height growth. Container seedlings averaged 78 percent in height growth and bare-root, 56 percent (Boyer 1988). This increased to 94 percent of all seedlings after 5 years. Significantly more container (98 percent) than bare-root (91 percent) seedlings were in active height growth, and also significantly more released (95 percent) than unreleased (93 percent) seedlings, although differences at 5 years were minor compared to those at 3 years. In another year, it is unlikely that there will be any remaining treatment effects on percentage of seedlings in height growth.

Average seedling height increased from 1.3 ft at 3 years to 5.4 ft at 5 years (table 3). The height of container seedlings at 5 years (6.0 ft) still significantly exceeded the height of bare-root seedlings (4.9 ft), and the height of released seedlings (6.4 ft) still significantly exceeded the height of unreleased seedlings (4.4 ft). Release was more beneficial with the low than with the high level of site preparation. Low site preparation plus release was slightly better, in terms of seedling growth, than high site preparation alone. Container seedlings had a greater response to release than bare-root seedlings (2.5 ft for container vs. 1.3 ft for bare-root). Therefore, released container seedlings averaged 1.7 ft greater in height than released bare-root seedlings, and unreleased container seedlings had only a 0.5 ft height advantage over similar unreleased bare-root seedlings.

Table 3.--Average seedling height at end of fifth year in the field in relation to seedling type, site preparation, and release[1]

Seedling type	High site prep.		Low site prep.		
	Release	No release	Release	No release	Average
	feet				
Nursery	5.7	5.2	5.3	3.2	4.9
Container	7.8	5.8	6.7	3.7	6.0
Average	6.8	5.5	6.0	3.4	5.4

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[1] Seedlings not in height growth considered to have zero height.

Table 4.--Average seedling height at end of fifth year in the field, by treatment, for each study location

Location	High site prep.		Low site prep.		
	Release	No release	Release	No release	Average
	feet				
	Nursery Stock				
Butler	3.1	3.7	3.3	2.0	3.0
Valdosta	6.9	4.8	6.3	3.5	5.4
Waycross	6.0	7.0	7.1	5.2	6.3
Soperton	7.0	5.1	4.6	2.2	4.7
Albany	--	--	2.4	0.3	1.4
	Container Stock				
Butler	3.7	3.3	4.8	2.2	3.5
Valdosta	8.5	4.6	7.3	4.7	6.3
Waycross	10.5	10.0	9.2	4.4	8.5
Soperton	8.6	5.4	5.5	3.3	5.7
Albany	--	--	3.9	1.1	2.5

Seedling heights for each treatment combination and location are given in table 4. For the first time, at year 5, location (block) significantly affected seedling height. Apparently, this was the earliest expression of site quality because seedlings on flatwoods sites with a high water table (Valdosta, Waycross) were much taller (6.6 ft) than those on sandy upland sites at Butler and Soperton (4.2 ft).

CONCLUSIONS

Cultural treatments should be aimed at improving longleaf seedling survival during the critical first year after planting. Eighty-three percent of total 5-year seedling mortality occurred during the first year after planting and 92 percent by end of the second year. The significant effects of cultural treatments, as well as type of planting stock, on seedling survival did not extend beyond the second year. Container seedlings in this study were better able to endure harsh environmental conditions during the establishment period. After 5 years in the field, 76 percent of container seedlings had survived, compared to 51 percent of bare-root seedlings.

Superior field performance of container over bare-root seedlings has been reported before, which suggests that container seedlings may well have a pronounced survival advantage over bare-root seedlings during the establishment period. Goodwin found that longleaf pine container stock survived and grew better than bare-root stock on both a sandhills (Goodwin 1980) and a lower coastal plain site (Goodwin 1976). Observations of containerized and bare-root red pine seedlings subjected to drought revealed consistently less internal moisture stress in container than in bare-root seedlings (Becker and others 1987).

Post-planting release with a herbicide is an effective treatment for promoting rapid early growth of planted longleaf pine. Release was most important for seedlings with low site preparation, and this treatment resulted in taller seedlings than those subjected to high site preparation alone. Release boosted fifth-year height of seedlings with low site preparation by 76 percent and seedlings with high site preparation by 24 percent. Level of site preparation did not significantly affect the fifth-year height of either bare-root or container seedlings. Most of the competition on planting sites was herbaceous vegetation, which was unaffected by level of preplanting site preparation.

The height growth of container seedlings, at least through 5 years, may exceed that of bare-root seedlings. Container seedlings at 5 years averaged 6.0 ft in height and bare-root seedlings, 4.9 ft. Moreover, release promoted a greater growth response from container than from bare-root seedlings. Released container seedlings (7.2 ft) were 32 percent taller than released bare-root seedlings (5.5 ft), and unreleased container seedlings (4.7 ft) were only 13 percent taller than similar bare-root seedlings (4.2 ft).

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DEPTH OF PLANTING AND J-ROOTING AFFECT LOBLOLLY PINE SEEDLINGS UNDER STRESS CONDITIONS[1]

John C. Brissette and James P. Barnett[2]

Abstract.--Field performance of bare-root stock is affected by seedling root orientation and planting depth, and the effects are most apparent when water stress occurs after outplanting. The effects of planting straight or J-rooted loblolly pine (Pinus taeda L.) seedlings at three depths relative to the root collar, with well-watered or water-deficient conditions imposed in greenhouse water stressed beds over a 12-week period, are described in this paper. The results indicated that shallow-planting, regardless of root orientation, and J-rooting can cause mortality. Only a small percentage of the surviving shallow-planted, water-stressed seedlings exhibited any shoot growth. Also, fewer of the surviving J-rooted seedlings had shoot growth, and their average growth was less than that of the straight-planted seedlings. It was concluded that trees planted with their roots oriented downward will outperform J-rooted stock.

INTRODUCTION

The role of bare-root seedling root development has been the subject of many studies since Rudolf (1939) first related field performance to root deformation caused by planting. Two common deformities caused by planting are J-roots and L-roots. J-rooting results when a seedling is planted such that the root system is bent into the shape of a "J" by the bottom of the planting hole. The "L" root often results from machine planting and is characterized by a single 90° turn in the root system. Transport in both the xylem and the phloem can be restricted at the point of deformity.

The literature on root deformation of southern pines is inconclusive. Gruschow (1959), Little and Somes (1964), Mexal and Burton (1978), and Harrington and others (1987) all found that most excavated bare-root seedlings exhibited either taproot or lateral root deformation. However, only Harrington and others (1987) could relate shoot growth to patterns of root orientation. Results with other species, for example 2-0 spruce [Picea abies (L.) Karst.] (Lacaze 1968), indicated that J-rooting significantly reduced shoot growth during the first 2 years in the field. To complicate the issue even more, better shoot growth has been found in loblolly pine seedlings with deformed roots (Hay and Woods 1974). This may have been because larger seedlings, with their larger roots, are more easily misplanted, but they are likely to maintain their height advantage over smaller seedlings despite deformed roots (Wakeley 1969). However, the long-term effects of root deformation have not been ascertained.

Several State forestry agencies are now having problems justifying contract specifications against J- or L-rooting of seedlings during planting. Most States have specifications prohibiting J- and L-rooting, but research and documentation to justify these specifications are inconsistent. Field studies have been difficult to interpret because of environmental conditions following planting; for example, abundant rainfall may prevent any critical evaluation of planting techniques.

The objectives of this study were to evaluate the effects of J-rooting and depth of planting on survival and initial growth of loblolly pine (Pinus taeda L.) seedlings when planted in water-stressed beds where moisture availability could be controlled.

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[1] Paper presented at Southern Silvicultural Research Conference, Memphis, Tennessee, November 1-3, 1988

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MATERIALS AND METHODS

The study was conducted in four sand-filled beds located in a greenhouse at the Alexandria Forestry Center in Pineville, Louisiana. The beds are isolated from the soil beneath the structure and from each other. Thus, the availability of moisture is totally controlled with irrigation. The beds are approximately 2.5 by 2.5 m in area, about 36 cm deep around the perimeter, and slope to a central drain at about a 41-cm depth. Water that infiltrates through the sand collects in a reservoir and is removed by a sump pump. At a spacing of 15 by 15 cm, each bed will hold 240 seedlings.

The 1-0 loblolly pine seedlings used in this study were grown at the USDA Forest Service's W. W. Ashe Nursery near Brooklyn, Mississippi, with seeds from the Forest Service's Louisiana seed orchard source. The seedling roots were pruned at 15 cm below the root collar before planting.

In this study a split plot experimental design was used, with water stress applied to the whole bed and three levels of planting depth and two types of root orientation applied within each bed. The experimental units were noncontiguous plots each with 40 seedlings planted at random within each bed. There were six plots per bed. Two beds were chosen at random to be well-watered controls kept near field capacity throughout the study. The other two beds were watered at least daily for 1 week after planting to ensure that there were no air pockets around the planted roots. Water was then withheld from these latter two beds until overall survival of the stressed treatments fell below 50 percent. Survival was recorded at 4, 6, and 8 weeks after planting. By 8 weeks the overall survival of the stressed beds was 38.2 percent. A 4-week recovery period followed with all four beds maintained near field capacity.

The depth of planting was controlled by marking the wood dibbles used for planting. For planting straight roots, a line used to align the root collar was marked 15 cm from the bottom of the dibble. Additional marks were put 2 cm below that line and 3 cm above it. When a seedling was held with its root collar at the indicator line it could be accurately planted at the root collar, shallow-planted with the root collar 2 cm above the soil surface, or deep-planted with the root collar 3 cm below the soil surface.

The dibble used to plant J-rooted seedlings was constructed with similar guides to align the root collar, but here the bottom of the dibble was rounded and grooved to hold the roots in a "J" shape during planting. The radius of the dibble at the base of the J was approximately 1 cm. When planting the J-rooted seedlings, a straight dibble was used first to open a hole so that root damage was minimized.

Because planting depth was based on where the root collar was placed relative to the soil surface, the bottom of the planting slot was not as deep for the J-rooted seedlings as for the corresponding straight-planted ones. For the straight root orientation, the bottom of the planting slots were 13, 15, and 18 cm deep for the shallow, at root collar, and deep planted treatments, respectively. The corresponding depths for the J-rooted seedlings were 8, 10, and 13 cm. The only overlap, therefore, was between the shallow straight roots and deep-planted J-roots.

In addition to a final survival measurement taken at 12 weeks after planting, the proportion of surviving seedlings within an experimental unit that had new shoot growth was tallied, and the length of the new growth was measured.

Several environmental variables were monitored and recorded hourly using an electronic data logger. Soil moisture at 10 cm below the surface was measured with a resistance block at one location in each bed. Soil temperature was measured in one of the beds at 5 and 10 cm. Air temperature and relative humidity at seedling height were also measured.

The data were analyzed using analysis of variance (ANOVA). Because survival was measured at 4, 6, 8, and 12 weeks, a repeated measures ANOVA was used for analysis of survival.

Because repeated measures are correlated, it is necessary to check the validity of the F-tests of the terms in the ANOVA model that include time as a factor. If the convariance matrix of the measurement errors of the time intervals meet the Huynh-Feldt (H-F) condition, then the usual F-test results apply (Milliken and Johnson 1984). If the H-F condition is not met, then an adjusted F-test can be applied or a multivariate ANOVA can be used (Milliken and Johnson 1984). In this study, the H-F condition was not met, so adjusted F-tests were used for those terms that included weeks after planting as a factor.

Where planting depth was significant, regression was used to evaluate the trend with the values -2, 0, and 3 corresponding to shallow, at the root collar, and deep planting, respectively. When the response measured was a proportion, it was transformed to the arc sine (in radians) of the square root of the value. This transformation ensures that the proportions are close to being normally distributed with homogeneous variance (Freese 1967). Because of space limitations in the greenhouse, the whole plots had only two replications. Therefore, a significance level of 0.10 was used to provide greater power for detecting treatment differences than the more commonly used 0.05 level.

RESULTS

Survival

Because there were only two replications of the whole plot, there were insufficient degrees of freedom for error to test the weeks after planting by stress interaction effect on survival. Of the other two-, three-, and four-way interactions, only the weeks after planting by planting depth effect was significant. After correcting for the H-F condition, the significance level of the interaction was 0.04, with a mean square error (MSE) of 0.0225 and an F value of 2.62 with 6 and 10 degrees of freedom.

For an understanding of the effect of weeks after planting and planting depth on survival, a quadratic response surface regression was performed. The estimated response surface is shown in figure 1. It is apparent that survival of shallow-planted seedlings continued to decline between 4 and 12 weeks, while essentially all the mortality among the deep-planted trees was seen within the first 4 weeks after planting. Seedlings planted at the root collar had an intermediate response.

Water stress, depth of planting, and root orientation were all significant (table 1). Root orientation did not interact with the other factors. Overall survival at 12 weeks for straight-planted seedlings was 51.6 percent, and for J-rooted seedlings overall survival was 35.0 percent (F=20.7, df=1,10 for p=0.001). Stress and depth of planting had an interaction effect on survival (F=2.99, df=2,10 for p=0.096). Although the stressed seedlings had poorer survival than the controls at each planting depth, the interaction was significant because the difference was somewhat greater for shallow-planted than for deep-planted trees (fig. 2).

Growth

The proportion of the surviving seedlings that had new shoot growth 12 weeks after planting was significantly affected by the treatments (table 1). Depth of planting interacted with both water stress and root orientation. With a MSE=0.0122 for the subplot and interaction effects, the depth by stress interaction had an F of 9.46 and a p of 0.006. When straight and J-rooted seedlings were combined, planting depth had little effect if the seedlings were not water stressed, but if stressed, the shallow-planted treatments had a marked decrease in the percentage of seedlings that grew (fig. 3).

The depth by root orientation interaction had an F of 5.74 and a p of 0.025. For the straight-planted treatments, the proportion that grew increased only slightly between the shallow-planted and those planted at the root collar, whereas among the J-rooted treatments, the proportion increased steadily with greater planting depth (fig. 4).

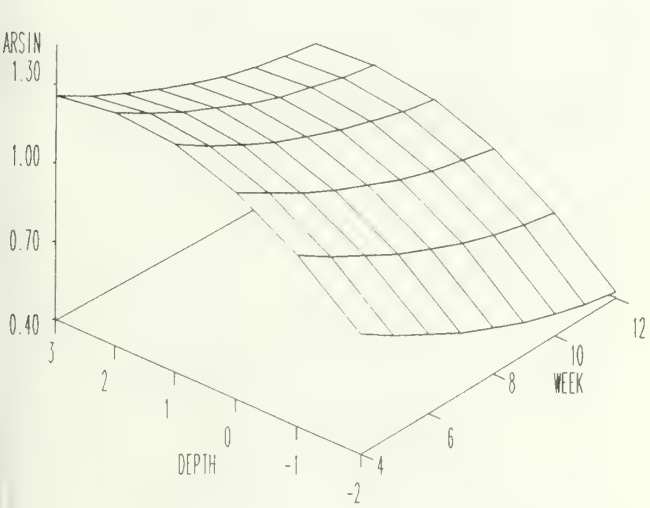

Figure 1.--Interaction of planting depth (in cm from the root collar) and weeks after planting on the survival of loblolly pine seedlings (arc sine percent) planted in sand-filled beds in a greenhouse.

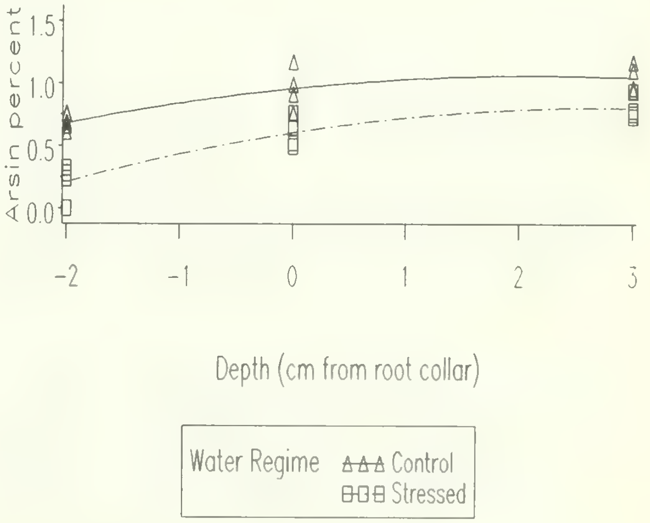

Figure 2.--Interaction of planting depth and watering regime on the survival of loblolly pine seedlings (arc sine percent) 12 weeks after planting in sand-filled beds in a greenhouse.

Table 1.--The effect of water stress, depth of planting, and root orientation on the survival and growth of loblolly pine seedlings 12 weeks after planting in a greenhouse. See text for discussion of significant differences

Stress Level	Planting depth	Root orientation	Survival	Survivors with shoot growth	Mean new growth
			------percent------		----mm----
Well-watered	Shallow	Straight	43.8	67.8	65
		J-root	35.0	39.2	56
	Root collar	Straight	77.5	67.2	82
		J-root	55.0	48.9	64
	Deep	Straight	82.5	66.6	75
		J-root	61.8	61.9	56
Water-stressed	Shallow	Straight	29.2	29.1	68
		J-root	0.3	0.0	--
	Root collar	Straight	60.2	60.2	73
		J-root	36.1	35.5	38
	Deep	Straight	57.5	58.4	65
		J-root	56.8	56.8	65

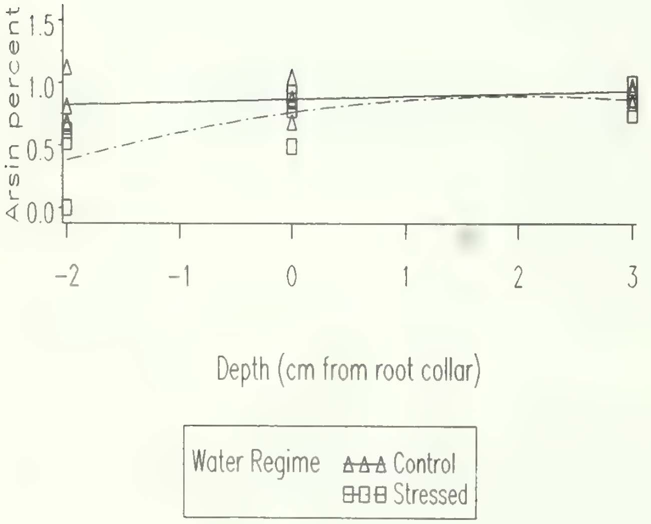

Figure 3.--Interaction of planting depth and watering regime on the proportion of surviving loblolly pine seedlings (arc sine percent) with new shoot growth 12 weeks after planting in sand-filled beds in a greenhouse.

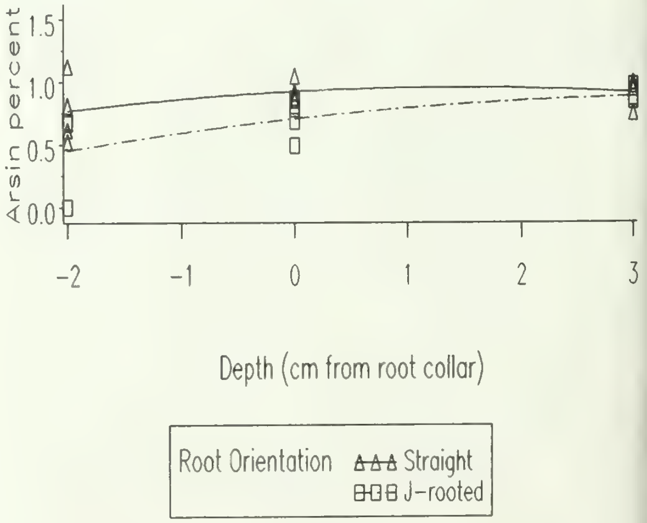

Figure 4.--Interaction of planting depth and root system orientation on the proportion of surviving loblolly pine seedlings with new shoot growth (arc sine percent) 12 weeks after planting in sand-filled beds in a greenhouse.

Among the seedlings with new shoot growth, the average length of elongation at 12 weeks after planting was also influenced by the treatments (table 1). There was a significant three-way interaction among the factors studied (MSE=87.49, F=3.70, and p=0.086). The effect of the interaction on mean height growth is shown in figure 5. Among the well-watered treatments, the straight-planted seedlings consistently grew more than the J-rooted seedlings. The stressed and J-rooted seedlings had no new growth if shallow-planted but did not differ from the other treatments if deep-planted.

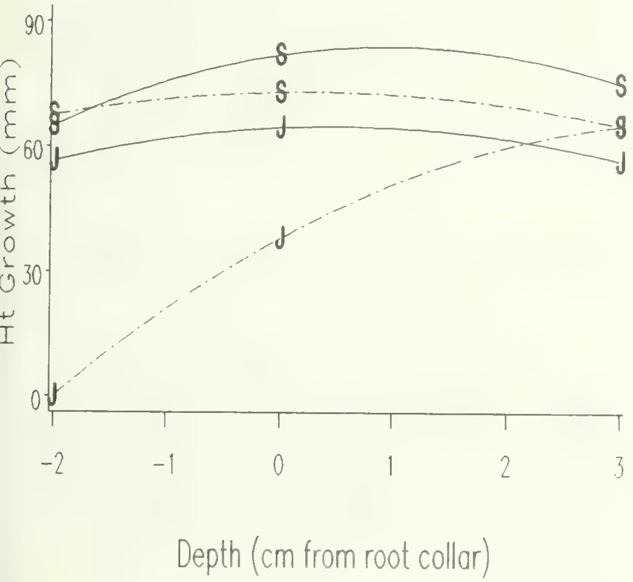

Figure 5.--Interaction of planting depth, watering regime (solid line=well watered, broken line=stressed), and root orientation (S=straight, J=J-rooted) on the average stem elongation of loblolly pine seedlings that had shoot growth 12 weeks after planting in sand-filled beds in a greenhouse.

Although the surface of the sand in the water-stressed beds became very dry, the resistance blocks at 10 cm indicated that, throughout the study, the soil water potential did not fall below -0.5 bars (field capacity) in any of the beds. Thus, except for the shallow-planted, J-rooted seedlings, water should have been available to at least part of the root systems during the 12 week study. The total volume of sand from which water could be extracted depended on how quickly and how much new root growth a seedling was capable of sustaining. Soil temperature did not limit root growth. At the 10 cm depth, temperature ranged from 11.2 to 29.4 °C and averaged 21.0 °C during the study.

DISCUSSION

The most important conclusion that can be drawn from this study is that under the treatment combinations where the root systems were deep enough to have available water, the straight-planted seedlings consistently outperformed the J-rooted trees. These results suggest the following hypotheses: (1) water uptake by deformed root systems is less efficient than uptake by downward-oriented straight root systems, and (2) new root growth and subsequent exploitation of additional soil volume is less for J-rooted seedlings. Hay and Woods (1978) found that root deformation of loblolly pine seedlings impeded carbohydrate translocation below the restriction. Because carbohydrates are needed in abundance by growing tissue, J-rooting could reduce the proportion of the root system capable of renewed growth.

When designing this experiment we were faced with two choices for designating planting depth: the root collar or the bottom of the planting hole. Unfortunately we could not do both due to the space available for the experiment. We chose the root collar as our basis for determining depth and thereby confounded depth to the bottom of the planting hole with root orientation. The alternative, however, would have confounded the transpirational surface area with root orientation.

Regardless of watering regime, seedlings in this study were under greater water stress than seedlings planted in the field because conditions in the greenhouse were hotter and dryer than outside. Together, air temperature and relative humidity determine the vapor pressure deficit (VPD), which is the driving force for evapotranspiration. Therefore, the amount of transpirational surface area exposed is an important consequence of planting depth.

A summary of the greenhouse air temperature and relative humidity data showed that, although there was some day-to-day variation, VPD tended to be greatest during the early afternoon. Daily VPD at 1400 hours (central standard time) in the greenhouse averaged 2.3 times greater than at a field site 32 km away. This implies that the root systems of the seedlings that died were unable to take up water fast enough to replace that lost through transpiration, not that soil water became unavailable.

The effect of planting depth on water uptake under the conditions of this study was probably related to the amount of root system that was in the zone of available water. Although the bottom of the planting hole was the same for the shallow-, straight-planted and deep-planted, J-rooted seedlings, a greater proportion of the root system of the shallow-planted seedlings was near the surface. Under the well-watered treatment, some of the shallow roots were in a zone where evaporation from the surface probably resulted in a greater demand for water than uptake by the roots. In the stressed treatment, the shallow roots were in relatively dry soil. In both cases the deep-planted, J-rooted seedlings survived better, had about the same proportion of survivors with new shoot growth, and had similar mean height growth as the shallow-planted seedlings with straight roots.

How seedlings are planted can have both short- and long-term implications for plantation success. Usually the first year survival is of most immediate concern. Planting depth is critical. On well-drained sites, deep planting is usually recommended (Dierauf 1984, Williston and Ursic 1979). The results of our study agree with these earlier findings. However, on poorly drained silts and clays, planting the root collar at or only slightly below the soil line is best (Switzer 1960). Based on our results we conclude that J-rooting will reduce survival and initial growth under water-stressed conditions.

Over the longer term, the detrimental effects of J-rooting are perhaps more important. Height growth of loblolly and shortleaf pines (P. echinata Mill.) through age 7 was not as good for trees with deformed roots as for trees with roots oriented downward (Harrington and others 1987). Also, roots deformed at the time of planting can reduce tree stability throughout the life of a stand (Chavasse 1978, Grene 1978).

There is convincing evidence that seedlings planted at the proper depth for the site and with their roots oriented downward will outperform trees with poor root orientation. Care in planting will result in more productive plantations. Everyone involved in tree planting, from the contact specialist to the planting crew supervisor and the individual tree planters, should work to ensure that seedlings are planted properly.

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ECONOMICS OF NATURAL REGENERATION ON THE PIEDMONT PLATEAU[1/]

M. Boyd Edwards and Coleman W. Dangerfield[2/]

ABSTRACT.--Cost-effective regeneration alternatives are urgently needed for NIPF land on the Piedmont Plateau. Four methods of natural regeneration are examined by profitability analysis. These methods of regeneration are shown to be good investments, but internal rates of return are higher for natural regeneration (10.8% per year) than for site preparation and planting (10.1% per year after taxes and adjustment for inflation).

INTRODUCTION

Natural methods are the cheapest for regenerating loblolly pine on Piedmont sites, but how good an investment is natural regeneration?

The economic analysis reported here compares profitability of natural regeneration with that of site preparation and planting on a typical Piedmont site.

Some of the data for this study came from a previous study of regeneration alternatives for loblolly pine stands on non-industrial private forest (NIPF) land (Edwards 1987a). A majority of the forest land in the region falls into this ownership class and these forest landowners must regenerate pine after harvest if the demands for pulp, fiber, and timber are to be met for the next century.

REGENERATION STUDY

In the regeneration study, six treatments were replicated five times in a randomized block design. Treatment plots were 2 acres in size. Treatments were:

1. Clearcut with seed in place, no preharvest burn (control).
2. Clearcut with seed in place, preharvest burn.
3. Seed tree cut with 8-10 good seed trees per acre left after harvest, no preharvest burn.
4. Seed tree cut as above, preharvest burn.
5. Shelterwood cut leaving 25 ft^2 b.a./acre, no preharvest burn.
6. Shelterwood cut as above, with preharvest burn.

Results from that original study showed:

One year after harvest, the number of seedlings established per acre ranged from 200 on the seed tree and burn treatment up to 650 on the shelterwood treatment (table 1), but did not differ significantly among treatments. In the year of treatment (1983) seed production was poor. Production was good in 1984 and 1985, and seedling establishment increased rapidly. In some cases, too many seedlings were established, but numbers could have been limited by cutting seed trees and shelterwood trees in 1985.

Table 1.--Mean number of pine seedlings per acre for each of 3 years after harvest, by treatment, Piedmont Georgia.

		Year	
Treatment	1984	1985	1986
	--------Seedlings/acre----------		
Clearcut	400 a	1,850 c	1,250 b
Clearcut and burn	400 a	3,100 c	2,550 b
Shelterwood	650 a	5,900 ab	4,700 b
Shelterwood & burn	550 a	9,350 a	10,000 a
Seed tree	550 a	4,900 bc	3,900 b
Seed tree & burn	200 a	6,950 ab	5,000 b

Means followed by the same letter do not differ significantly at the 0.05 level.

[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2/] Authors are Research Ecologist, Southeastern Forest Experiment Station, USDA Forest Service, Dry Branch, GA; Economist, Division of Agricultural Economics, the University of Georgia, Athens,GA.

The original study demonstrated that natural regeneration methods work in the Piedmont Plateau because Table 1 shows all treatments were successful and exhibited the potential to establish an adequately stocked stand. The shelterwood treatment with preharvest burn produced the most seedlings after three years and would require some thinning in order to eliminate the competition among the young seedlings. The harvest of the seed trees from the site could be utilized to reduce this competition by flagging drag lines to loading decks through these areas with too many young seedlings.

The original study also served to emphasize the importance of fire to natural regeneration in that all treatments that received a preharvest burn produced more seedings than the same treatment without the burn. The preharvest burn not only serves to reduce the competition from unwanted vegetation, but provides enough disturbance for a suitable seedbed. The seedbed preparation with fire greatly improves the chance of germination of the seeds and helps insure the survival of the seedlings.

A final statement about the original study emphasizes the importance of selecting the best trees from the stands to serve as the seed trees. These trees should have deep root systems, wide crowns, and be disease free. If these criteria are met, they will serve to regenerate the site and continue to appreciate economically for the landowner.

FATE OF SEED TREES

Many landowners fear damage to seed trees during and after the main stand is harvested. One of our purposes, therefore, was to observe survival and growth of seed trees and shelterwood trees over a 5-year period, which is normally sufficient to establish natural regeneration.

Diameter, height, and condition of the original 567 leave trees were measured before treatment in 1982 and remeasured in 1987, immediately before they were harvested.

Overall condition of seed trees was good 5 years after harvest (table 2) 93% of the original trees were healthy, 1% had some damage, and only 6% were dead. The major causes for damage or death were southern pine beetles and lightning.

Diameter, height and volume growth of the seed trees was satisfactory (table 3). Since outstanding trees were left, these is no reason to belive that a logger would not have paid well for them after a new stand was established.

Table 2.--Number and condition of leave trees at time of original harvest and 5 years later.

Treatment	Number of trees left 1982	1987 Healthy	Damaged	Dead
Seed tree	90	88	0	2
Seed tree/burn	89	76	2	11
Shelterwood	191	174	4	13
Shelterwood/burn	197	187	1	9

Table 3.--Mean DBH, height, and volume growth of leave trees in the 5 years after

Treatment	Mean DBH growth Inches	Mean height growth -Feet-	Mean volume growth Cubic Feet
Seed tree	1.2	11.3	18.7
Seed tree/burn	1.1	10.6	15.5
Shelterwood	0.9	10.2	14.1
Shelterwood/burn	1.1	10.8	14.2

CASH FLOWS AND RATES OF RETURN

Cash flows and rates of return were computed to compare natural regeneration with site preparation and planting after harvest. Wood flow estimates and financial calculations were performed using Yieldplus (v1.1b) (Hepp 1988). Site index of study area was 90 ft. at age 50. The surviving planted stand density was set at 918 trees/acre as per Campbell 1985. The Yieldplus (v1.1b) growth model used was for a cutover loblolly pine plantation site. Site index is same as for the planted loblolly site. The surviving stand density at age 20 was set at 1000 trees/acre as per Edwards 1987b. Basal area was set at 156 ft^2/A at age 20 as per Campbell 1985. The Yieldplus (v1.1b) growth model used was for naturally occurring loblolly pine. Wood volume differences between the cutover site and the naturally occurring site are similar to those reported by Campbell 1985.

Financial parameters were established and some assumptions made as follows:

1. A 30-year rotation for the site preparation and plant scenario (1988-2018).
2. A 31-year rotation for the natural regeneration because our previous study showed that we did not get adequate regeneration the first year (1988-2019).
3. All capital gains taxed at 28% of total gain.
4. A discount rate of 8.0% before taxes and 5.8% after taxes.

5. Stumpage prices:

Product	Price
Small sawtimber (13 to 19 inches d.b.h.)	$160/MBF
Large sawtimber (20 to 36 inches d.b.h.)	175/MBF
Pulpwood	16/cord
Chip-N-Saw	40/cord

The financial transactions for the silvicultural operations were:

Expense	Nat. regen.	Site prep and plant
Management[1]	$2.00/acre	$ 2.00/acre
Site prep. burn[2]	5.00	5.00
Competition control[3]	75.00	75.00
Planting[4]	0.00	75.00
Prescribed burn (begin at 15 years)[5]	5.00	5.00
Harvest	20.39(2009)	30.99(2008)
Harvest	80.26(2019)	99.15(2018)

At about 20 years into the rotation a thinning is desirable to generate some capital and to improve growth in the stand. There are expenses for harvest $20.39/for natural regeneration and 30.99/acre for site preparation and planting. This is figured on being 10% of harvest value. At the end of the rotation, clearcuts are planned in years 2018 and 2019. At 8% of harvest value, the expenses are $80.26/acre for natural regeneration and $99.15/acre for site preparation and planting.

Expected revenues from harvest are:

Harvest year and product	Natural regeneration revenue	Site preparation and planting
20 - Pulpwood	$189.54/acre	$229.34/acre
20 - Chip - N - Saw	14.33	80.53
30 - Pulpwood	329.32	272.58
30 - Chip - N - Saw	541.76	695.46
30 - Sawtimber	132.11	271.35

The inflation rate was assumed to be 2% for ordinary deductible expenses like cost for the management plan and the prescribed burning. This rate was computed as a composite of the specified sawtimber and pulpwood inflation rates according to the product mix.

The total net cash flow, which included all cash transactions before taxes, was estimated.

Total net cash flow was $1172.12/acre for clearcutting, site preparation and planting and $932.42/acre for natural regeneration. Cash flow was 20.45% less for natural regeneration than for site preparation and planting, but costs of natural regeneration also were lower. Internal rates of return were computed to compare the alternatives.

These values, adjusted for inflation and for taxes at end of the rotation were 10.8% for natural regeneration and 10.1% for site preparation and planting. It would appear that natural regeneration may be at least as good an investment as site preparation and planting.

Natural regeneration is not for everybody or for every situation. For the NIPF owner, however, it reduces outlays early in the rotation. Large outlays for site preparation and planting dissuade many NIPF owners from any form of regeneration after their harvests. Natural regeneration, therefore, represents a more practical opportunity for NIPF owners.

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[1] $2.00/acre for a consultant to advise the landowner about silvicultural practices.

[2] $5.00/acre to prepare the seedbed in natural regeneration, in site prep and plant burning would be conducted after harvest and before planting.

[3] $75.00/acre for all treatments except fire control of unwanted vegetation at or before the new stand established.

[4] $75.00/acre to plant seedlings. The only major expense difference between the two methods is that planting is not required in natural regeneration.

[5] $5.00/acre for prescribed burning at stand age 15 (2003 for site preparation and planting and 2004 for natural regeneration) and at 3-year intervals until end of the rotation.

METHODS FOR INCLUDING RISK IN SPECIES-SITE SELECTION DECISIONS[1]

Jon P. Caulfield, Eugene Shoulders, B. Graeme Lockaby[2]

Abstract.--The mean-variance rule and stochastic dominance analysis are used to show how risk can be included in species-site selection decisions. Volumes of 20-year-old plots of loblolly, slash and longleaf pine were compared on wet, intermediate and dry sites. Longleaf pine was always outperformed by the other species. Slash outperformed loblolly on wet sites, and tended to have higher volumes on dry sites.

INTRODUCTION

On pine sites in the South, the decision of which species to plant is important. Proper matching of species to site influences growth performance and financial returns from the final timber crop. Generally, the site-species decision comes down to a choice between loblolly and slash pine, and to a lesser extent, longleaf or shortleaf pine.

Many managers plant the species predicted to have the highest average merchantable or financial yield on the site type in question. This decision rule, known as the expected value rule, is widely applied. The rule can be stated as follows: given two investment alternatives, F and G, F will be preferred to G if:

$$E(V_F) > E(V_G)$$

Where E(VF) and E(VG) refer to expected values of F and G, and these are measured in financial or volume terms. This preference for higher versus lower returns is logical, and in many cases results in a correct choice. But basing the site-species selection decision solely on average yields ignores risk.

Risk is a situation in which the outcome of a decision is not known in advance with certainty, but for which the probability distribution of outcomes is known (Knight 1921). Although the use of average yields implicitly recognizes that a probability distribution exists, mean yields do not describe the variability of this distribution and do not account for risk in the decision process. In fact, the exclusive use of average returns can easily result in an incorrect choice. This can be shown by considering two investment alternatives:

Investment:

F		G	
outcome	probability	outcome	probability
$100	0.5	-200	0.5
200	0.5	500	0.5

The mean return from either of these two possibilities, calculated as the sum of the product of the probabilities times the possible outcomes, is $150. Here $E(V_F)$ and $E(V_G)$ refer to the expected values, or mean outcomes. Given a choice of these two investment alternatives, many individuals would probably select possibility F because most people are risk averse. A risk averse person is someone who will not take a "fair" bet, such as this one. Even though the mean return is equal for both investments, F carries far less risk. For risk-averse individuals, the possibility of losing $200 is more painful than the pleasure that would be derived from winning $500. The risk averse person is different than what we term the "risk neutral" decision maker, who cares only about the investment with the highest average outcome. A risk neutral individual would be indifferent between these investments.

Frequently, the riskiness of different investment alternatives is simply ignored and decision makers select investments using only the mean. In other words, it is often assumed that decision makers are risk neutral, even though they may not be.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Many managers are not comfortable dealing with risk. This is probably due partly to the intuitive appeal of having to deal with a single parameter such as average return to make a decision. A second reason is that the analysis may turn up more than one "right" answer. In that case the manager is still in the situation where it is necessary to choose between more than one alternative.

MEASURING RISK

One commonly used risk measure was developed by Markowitz (1952). He showed that the mean and variance, respectively, often provide theoretically correct measures of returns and risk. Markowitz proposed the "mean-variance" rule ((E,V) rule) which states that, given investment alternatives F and G, F will be preferred to G if one of two situations holds, these being:

(1) $E(V_F) > E(V_G)$ and $\text{Var } F \leq \text{Var } G$

OR

(2) $E(V_F) \geq E(V_G)$ and $\text{Var } F < \text{Var } G$

where expected value is used as an index of profitability, and variance is the measure of risk. In practice, the standard deviation is often used in place of the variance. Since standard deviation is measured in the same units as the mean (e.g. dollars) it makes more intuitive sense to many decision makers.

Several assumptions are implicit in the (E,V) rule. One is that the distribution of returns is normal, or nearly so. The other major assumption is that investor preferences are such that they can be completely described by the mean and variance of returns. When these assumption are violated, the (E,V) rule may not discriminate among alternative investments satisfactorily.

A third situation that makes the (E,V) rule less than adequate in certain situations is when distributions with large means are associated with large variances. In such a case the following problem arises:

$$E(V_F) > E(V_G) \text{ and } \text{Var } F > \text{Var } G$$

Here, application of the (E,V) rule gives indeterminate results.

These shortcomings of (E,V) analysis led to the development of other decision rules. One important group is referred to in the literature as stochastic dominance analysis (SDA) (Quirk and Saposnik 1962, Hanoch and Levy 1969).

SDA requires a pairwise comparison of each probability distribution of returns for each investment alternative. Given a discrete probability mass function such as the following:

outcome	probability	cumulative probability
80	.2	.2
90	.2	.4
100	0	.4
110	.4	.8
120	.2	1.0

a distribution function can be plotted by arranging the outcomes and their respective probabilities in ascending order (fig. 1). This gives the probability that an outcome will be smaller than or equal to a specific value.

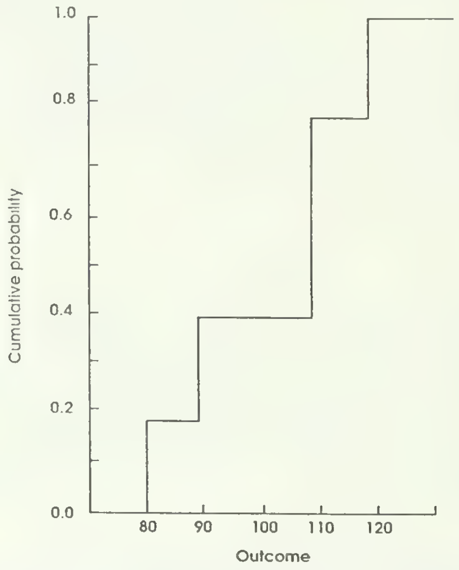

Figure 1.--The cumulative distribution function gives the probability that an outcome is less than or equal to a specific value.

As with any decision making tool, SDA makes use of certain behavioral assumptions. First degree stochastic dominance (FSD), assumes only that decision makers prefer higher returns to lower returns.

To use FSD, probability distributions of returns are presented as distribution functions. For distribution F to dominate distribution G, F must lie entirely to the right of G (fig. 2). In other words, there is always a higher probability of achieving a given level of returns with investment F than there is with G.

Often, distributions cross one another, and FSD will not apply (fig. 3). In other words, if it is assumed only that the decision maker prefers more to less, the FSD rule cannot be used when distributions cross. At this stage second degree stochastic dominance (SSD) is employed. SSD assumes that decision makers prefer more to less, AND are also risk averse.

To carry out SSD, distribution functions are still used. Now, however, the cumulative differences between each investment over the domain of returns are evaluated. Investment F is preferred to G for all risk averters if the cumulative difference between F and G is nonnegative over the entire domain of possible outcomes. Thus, even if there is some area in which the difference between the distributions is negative, as long as the sum of the differences over the entire domain of outcomes remains positive, F will still be preferable to G. In figure 3, the cumulative difference between F and G is positive, even though over part of the range of outcomes (Xo to X1) the difference is negative.

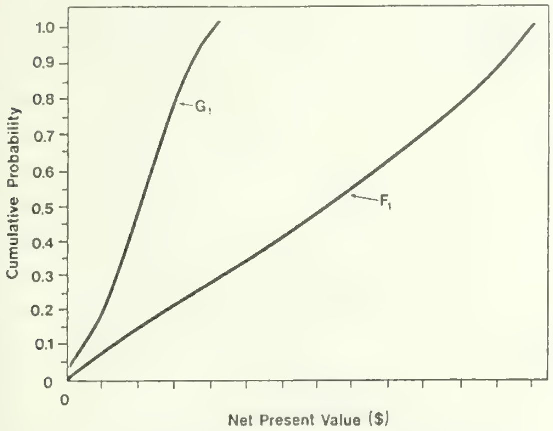

Figure2.--F dominates G by first-degree stochastic dominance because F_1 lies everywhere to the right of G_1.

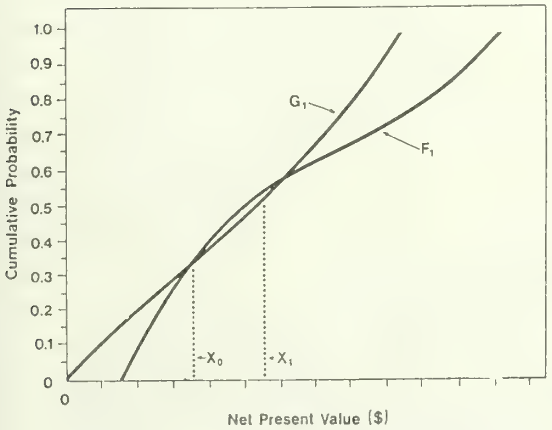

Figure3.--F dominates G by second-degree stochastic dominance because the cumulative difference between G_1 and F_1 is everywhere positive.

DATA

A species comparison trial of loblolly, slash and longleaf pine was established on three site types in Mississippi and Louisiana. The sites were characterized as wet, intermediate or dry. A complete description of site characteristics appears in Shoulders original paper on this study (Shoulders 1976).

Three plots of each species were planted at a 6'x6' spacing at each installation in a randomized complete block design. Plots contained either 11 rows of 11 trees each or 12 rows of 12 trees each. A total of 113 installations were initially planted. By age 20, however, various factors had reduced to 63 the number of installations on which two or more plots of two or more species could be compared for volume differences. Of the remaining installations, 37 were on intermediate sites, 17 were on wet sites and 9 were on dry sites.

Merchantable volumes at age 20 in cubic feet outside bark were computed from DBH and height inventories on all remaining plots. Volumes are reported in cunits per acre.

ANALYSIS

The expected value and (E,V) rules, along with first- and second-degree stochastic dominance analysis were used to compare volumes of each species on each of the three site types. The volume per acre for each species on each block is assigned a discrete probability of 1/n, where n refers to the total number of sample observations for each species on a site type. The volumes are arranged in ascending order, forming distribution functions for each species on each site type. This procedure is nonparametric and makes use of the findings of Mood and Graybill (1963), who showed that if n observations for a random variable are arranged in increasing order of size, the kth observation is a reasonable estimate of the k/(n+1) fractile. The empirical functions obtained are thus employed as estimates of the population distribution function.

There were a total of 24, 56 and 14 observations for each species on the final data set for the wet, intermediate and dry sites, respectively. The small number of observations on the dry sites would be expected to provide less reliable information about species selection decisions. It is included because it permits some comparison of the relative performance of all three species on this type of site.

RESULTS

Wet Sites

Figure 4 shows the distribution functions plotted for the three species on wet sites. Recalling that the distribution which tends to dominate is the one with the least area under it, it is seen that slash pine is far to the right of longleaf pine and somewhat to the right of loblolly, over most of the range of probabilities. The slash and loblolly distributions cross at the upper ends of volumes, and loblolly and longleaf cross at the extreme lower ends.

The results of the analysis are summarized in table 1. On wet sites, slash pine dominated both loblolly and longleaf pine using the expected value and mean-variance rules. Slash also dominated longleaf by FSD and loblolly by SSD. Slash had a higher mean volume and lower standard deviation than either of the other two species.

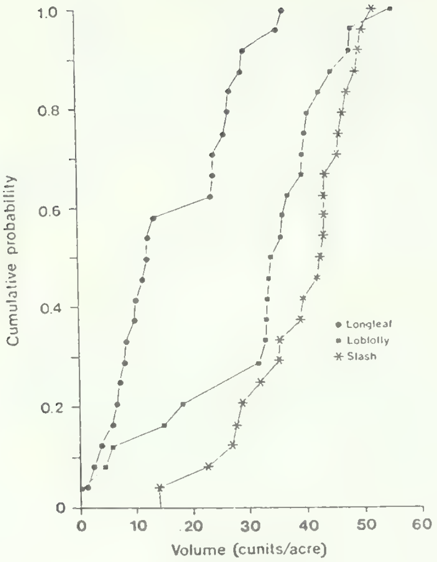

Figure 4.--Cumulative distribution functions of volume for wet sites.

Table 1.--Volumes and Risk Analysis -- wet sites

Species	Min.	Avg.	S.D.	Highest S.E.[1] Level	Dominates by: (E)[2]	(E,V)[3]
		(cunits/acre)				
Loblolly	0.37	36.41	9.30	1	LL	LL
Slash	13.81	42.11	6.87	2	LOB,LL	LOB,LL
Longleaf	1.30	18.45	9.84	-	--	--

[1] Stochastic efficiency.
[2] Expected value rule.
[3] Mean-variance rule.

Slash dominates longleaf by FSD because its distribution function is entirely to the right of it over all probability levels. But because the slash and loblolly pine distributions cross one another, SSD analysis must be employed. The cumulative difference between these functions will be greater than 0 over the entire range, therefore slash dominates loblolly by SSD.

Intermediate Sites

Figure 5 shows the distribution functions for each of the three species on intermediate sites. Once again, longleaf pine did not perform particularly well (table 2). Both loblolly and slash would be preferable using the expected value rule, and slash dominates longleaf using the (E,V) rule. Loblolly does not dominate longleaf using the (E,V) rule, because in addition to having a smaller mean, longleaf also had a smaller standard deviation than loblolly. But both loblolly and slash dominated longleaf by FSD.

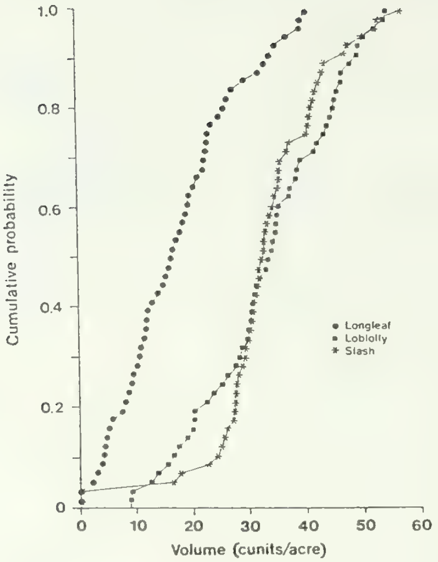

Figure 5.--Cumulative distribution functions of volumes for intermediate sites.

Table 2.--Volumes and Risk Analysis -- Intermediate Sites

Species	Min.	Avg.	S.D.	Highest S.E.[1] Level	Dominates by: (E)[2]	(E,V)[3]
		(cunits/acre)				
Loblolly	8.75	33.33	11.75	2	SL,LL	--
Slash	0.00	32.99	10.47	2	LL	LL
Longleaf	0.00	17.33	10.52	-	--	--

[1] Stochastic efficiency.
[2] Expected value rule.
[3] Mean-variance rule.

On the intermediate sites loblolly and slash were "second degree stochastic efficient," meaning that one is not strictly preferable to the other. The two distributions cross several times, and over part of their range the cumulative difference between the distributions is less than 0. Note, however, that when both species performed poorly, (leftwards tail of distribution) slash tended to perform less poorly. When they performed well, loblolly tended to outperform slash. This will be discussed in greater detail later.

Dry Sites

Longleaf pine is again dominated by both slash and loblolly by FSD and the expected value rule (figure 6 and table 3). But as would be expected, longleaf performs far better relative to slash and loblolly pine on dry sites than on intermediate or wet sites.

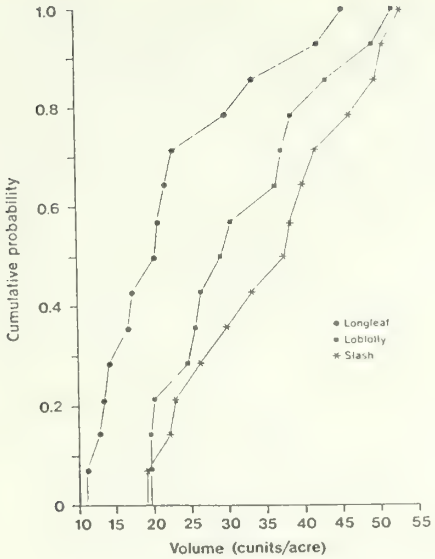

Figure 6.--Cumulative distribution functions of volume for dry sites.

Table 3.--Volumes and Risk Analysis -- Dry Sites

Species	Min.	Avg.	S.D.	Highest S.E.[1] Level	Dominates by: (E)[2]	(E,V)[3]
		(cunits/acre)				
Loblolly	19.47	32.43	10.40	2	LL	--
Slash	19.09	36.60	10.86	2	LOB, LL	LL
Longleaf	0.00	23.06	10.50	-	--	--

[1] Stochastic efficiency.
[2] Expected value rule.
[3] Mean-variance rule.

Slash dominates loblolly by the expected value rule on dry sites, but neither dominates by the (E,V) rule. Both species are also SSE. Slash had somewhat higher volumes than loblolly pine at most probability levels. However, slash also had a higher average volume and standard deviation than loblolly pine. Strict interpretation of the SDA ordering rules cannot rule out loblolly pine as a choice species, although its performance was generally inferior.

DISCUSSION

Taken at face value, the above results imply that: (1) longleaf pine should not be planted, (2) slash pine is preferable to loblolly pine on wet sites (3) slash and loblolly pine might both be appropriate on intermediate sites and (4) although both slash and loblolly are SSE on dry sites, slash tends to outperform loblolly pine.

The first implication is widely followed in practice. Relatively few acres are currently planted to longleaf because it is thought to suffer considerable post-planting mortality and can remain in the grass stage for several years.

Implication (1) is tempered, however, by several considerations. First, these trials were established in the mid 1950's and researchers have since learned to regenerate longleaf pine with greater success. On some sites, for example, weed control can make longleaf growth competitive with loblolly and slash pine because the grass stage is shortened considerably (Schmidtling 1987).

As regards implication (2), slash pine is generally thought to grow best on soils with poor internal drainage (USDA Forest Service 1965). On such sites, therefore, slash may tend to outgrow loblolly pine. This may be particularly true when the two species are compared within the natural range of slash pine. In this study, the majority of wet site installations were in the southeast corner of Mississippi, which is well within the natural range of slash pine.

Implication (3) suggests that although neither slash nor loblolly dominate on intermediate sites, each species individually may be a logical choice for outplanting, depending on the decision maker's attitude toward risk. Slash pine may be appropriate on intermediate sites for decision makers who are very averse to planting failures -- even if the planting does poorly, slash seems to give some kind of stand. Loblolly pine, however, may be logical on these sites for decision makers who are more concerned with obtaining higher average volumes.

Implication (4) supports conventional wisdom in the 1950's to prefer slash over loblolly on dry sites. But it must be remembered that there were far fewer observations on the dry sites than on the other two site types, so this implication must be interpreted very cautiously.

More generally, the results raise several points applicable to the entire study. First, enhanced classification of the soils involved in the study, in terms of series rather than general soil types, may better define soil factors which influence tree growth. Although categorizing general soils as done here provides an indication of relative species performance, more site-specific research might provide greater resolution of species-site relationships. Given sufficient observations for a specific soil group, performing an analysis such as this one would have better definition of soil characteristics.

Different Southern pine species do not respond identically to different types of site preparation and intermediate stand treatment. Here, no site preparation was carried out on the installations. As is now known, however, intensive site preparation often exerts a major influence on stand growth. Schmidtling (1987), for example, showed that cultivation and cultivation plus fertilizer treatment increased loblolly pine growth over slash at age 25. Slash outperformed loblolly on uncultivated control plots, however. In the context of this study, even though slash outgrew loblolly given no site preparation on a variety of sites, this should not be interpreted as a general result for different levels of site prep.

A third factor to consider is the intended rotation age of the trees. In this study volumes were calculated at age 20 because data were only available up to that age. But this is not necessarily the optimum biological or economic rotation for the stand. Basing a species-site selection decision on 20-year results may lead to an incorrect choice if a longer rotation is envisioned. Clason and Cao (1983), for example, compared growth and yield of slash and loblolly pine over a 31-year rotation. They found that thinned slash pine stands had higher average merchantable volume at age 21 than did loblolly pine. However, loblolly surpassed slash in volume by age 27, and continued to do so until age 31.

The results given by this risk analysis should not be interpreted as a blanket set of prescriptions. For the data considered here, however, the analysis provides information regarding the relative merits of different species selection decisions over a wide range of site types. More important, the analysis demonstrates how risk can explicitly be incorporated into stand establishment decisions, and how risk-averse decision makers can use such information to make species selection choices. More site specific analyses which incorporate a greater diversity of site preparation options and a wider range of rotation ages will permit opportunities to improve site-species selection decisions.

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MAKING EVERY TREE COUNT

SECRETS OF SEEDLING SURVIVAL[1]

Bruce L. Baldwin[2]

Abstract.--A system was developed for measuring the quality of tree planting as part of the management of the Conservation Reserve Program (CRP). This paper describes the results of reviews held in the 13 southern states in 1987 and 1988. The measurement of tree planting quality, and the addition or improvement of program elements such as vendor training and on-site inspection, resulted in a South-wide tree planting quality improvement of 31% in 1988 over 1987. Analysis indicates that the banning of root pruning in the field, making on-site inspections during planting operations and the requiring of vendors to take formal training had the greatest impact on improving overall tree planting quality.

INTRODUCTION

During the 1988 tree planting season over 800,000 acres were planted in the southern states under federal incentives programs. This was more than three times the amount planted just two years previously, due largely to the addition of a new program called the Conservation Reserve (CRP).

In an effort to maintain the quality of tree planting during this program expansion, program reviews were conducted in each of the 13 states in the South, with a focus on measuring the quality of planting. Each state was reviewed at the peak of both the 1987 and 1988 tree planting seasons.

The objectives of the reviews were:

1. Review USDA, Forest Service, and State Forestry Agency responsibilities for the technical aspects of tree planting for CRP.
2. Emphasize seedling handling and planting quality.
3. Reinforce the fact that reforestation is a system including:

   seed source, nursery handling, delivery system, technical assistance and planting.

4. Exchange information and successful techniques between State Forestry Agencies.

The intent was not to conduct a scientific study, but rather to administer a new program efficiently. Thus the data for any one individual state are not statistically significant. However, the amount of data collected across the South, together with consistent results among states suggest meaningful results.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Forest Incentives Specialist, USDA Forest Service, Cooperative Forestry, Atlanta GA.

METHODS

Agreement was obtained among the 13 states as to what constituted an acceptably planted tree and those attributes that would be considered unacceptable. It was considered important by most state forestry personnel for the seedlings to be fresh, tightly packed and vertically aligned. J, L or U rooting, shallow planting, loosely planted, excessively leaning and cull trees planted were considered unacceptable.

Using these criteria an estimate of tree planting quality could be quantified in terms of the percent of trees planted acceptably. In addition, data were also gathered for each farm on the type of planting tool used, whether the contractor had attended a training session, if pre-work conferences and on-site inspections had been made, and other items related to the history of the planting operation.

In each state at least two or three counties of high CRP activity were visited and at least a total of six farms were selected for inspection. Two to ten, 1/100 acre plots were sampled on each farm depending on the size of the farm. This resulted in the following samples being taken.

Table 1.--Number of samples by plot location, 1987 and 1988

Unit	1987	1988
	--Number--	
States	13	13
Counties	42	38
Farms	84	86
Plots	469	480

At each plot location all trees were checked for defective above-ground characteristics and tallied. Three trees were then selected from the population of apparently good trees. These trees were carefully dug up so that the roots could be examined. The product of the two percentages (above-ground x below-ground) was the percentage of acceptably planted trees.

RESULTS

The most dramatic result was that from 1987 to 1988, the number of acceptably planted trees in the 13 southern states increased from 65% to 76%. This translates to a measured improvement of 31% in the quality of tree planting (fig. 1). Many program elements contributed to this improvement, but the main driving force was a method for measuring the quality of the job which enabled the states to set goals and measure their progress toward attainment.

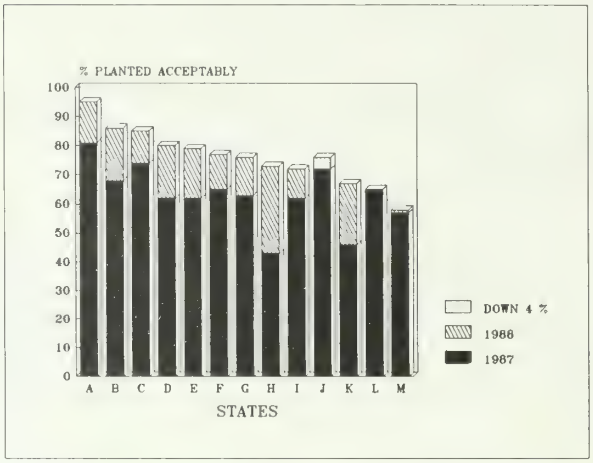

Figure 1.--Percent of trees planted acceptably 1987 and 1988.

Programs to train and certify vendors were important factors in obtaining quality planting. Plantings by trained or certified vendors averaged higher scores than non-trained, both in 1987 and 1988 (fig. 2).

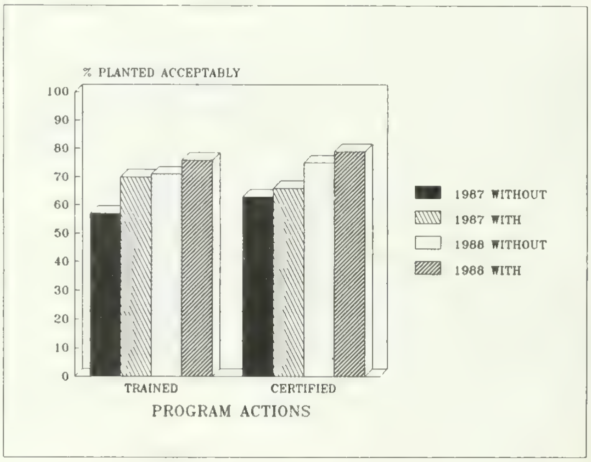

Figure 2.--Trees planted acceptably with the influence of trained and certified vendors 1987 and 1988.

Inspections and on-site pre-work conferences also had a positive influence on obtaining quality planting. Plantings where inspectors were present during the planting operation scored higher on average than plantings where inspections were made after the job was completed. This was true in both the 1987 and 1988 reviews (fig. 3).

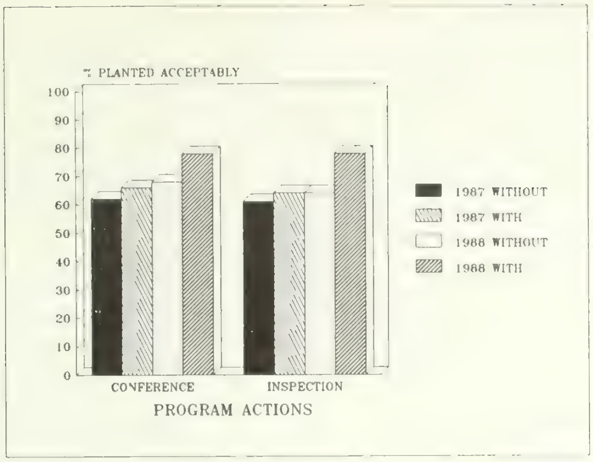

Figure 3.--Trees planted acceptably with the influence of on-site conferences and inspections 1987 and 1988.

On fields containing plow-pans, the practice of subsoiling improved the quality of planting by an average of 12% raising the score of the subsoiled fields 8 points over fields which were not subsoiled.

The pruning of tree roots in the field severely affected the quality of the planting where it occurred. Plantings where field root pruning was practiced averaged 18 points or 30% lower in score than those plantings where it was not permitted (fig. 4).

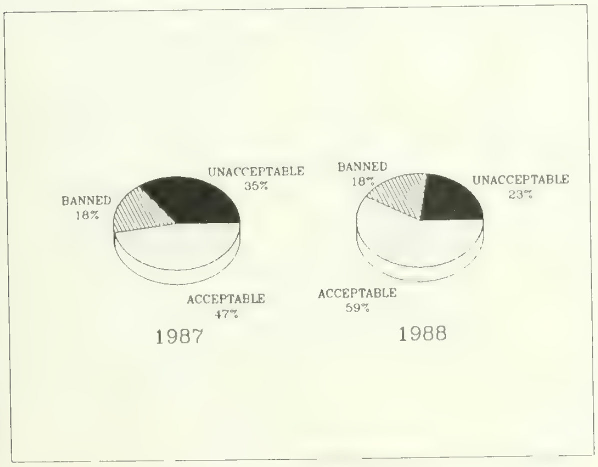

Figure 4.--Trees planted acceptably with the influence of banning field root pruning 1987 and 1988.

Hoedads and dibbles can be used to obtain equally high planting scores. However experience indicates that where there is no direct supervision over the quality of the planting job, machine planting will produce higher scores followed by dibble planting. Trees planted with hoedads scored lowest of the three planting methods (fig. 5).

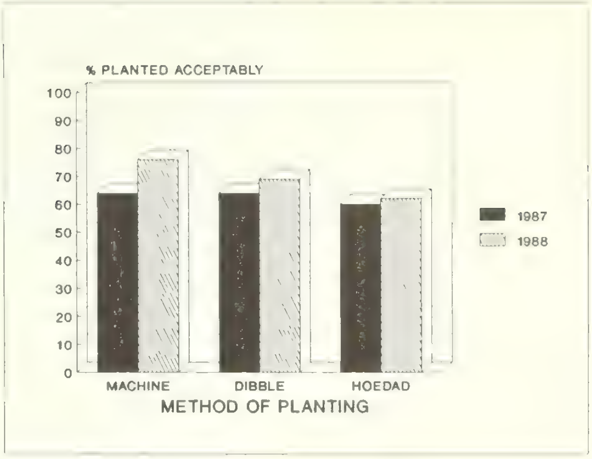

Figure 5.--Trees planted acceptably by method of planting 1987 and 1988.

CONCLUSIONS

Improvement in the quality of tree planting can be obtained by developing a system of measuring quality and then setting and striving toward measurable goals.

Field root pruning should not be permitted. Most trees do not need to be root pruned. When root pruning is necessary they should be trimmed to no less than 8 inches under controlled conditions at the nursery.

Planting of cull seedlings continues to be a problem. Best results were obtained by states where responsibility for culling was at the nursery. Most of the cull trees were planted when responsibility for culling was left with the contractor or tree planter.

The training of tree planting contractors in a workshop or meeting, and making on-site inspections during planting operations produced significant improvements in the quality of the planting in both 1987 and 1988.

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Pine Management

Moderator:

Emmett F. Thompson

Auburn University

TREE-RING SERIES RELATED TO STAND AND ENVIRONMENTAL FACTORS IN SOUTH ALABAMA LONGLEAF PINE STANDS[1/]

Robert Zahner[2/]

Abstract.--This study interprets changes in tree rings over the 22-year period 1964-1985 in natural longleaf pine (Pinus palustris Mill.) on the Escambia Experimental Forest in Alabama. A linear aggregate model was used to analyze absolutely-dated tree-ring measurements, describing five factors known to contribute to radial growth variance in southern pines: stand age, stand density, prescribed fire, site, and climate. Reduced ring widths were closely associated with current droughts and with years following winter burns. With stand age held at 25 years, basal area at 100 sq ft/ac and site index at 75, the model finds that climate and prescribed winter fires together account for 30 percent of the annual variation in radial growth[3/].

INTRODUCTION

This paper reports a tree-ring investigation of annual growth variation in two stands of longleaf pine (Pinus palustris Mill.) on the Escambia Experimental Forest (EEF) in Escambia County, Alabama. The objective was to establish the relative impacts on radial growth of intrinsic stand conditions such as age and stocking, and exogenous factors such as climate and prescribed fire. Such dendroecological analysis requires two data components (Fritts and Swetnam 1988): (1) tree-ring chronologies validated for the period of concern, and (2) measurements of environmental conditions as they vary over the period, in this case long-term weather records and documentation of stand treatments and site measurements.

METHODS

A long-term growth study had been established in young, evenaged stands of longleaf pine on the EEF in 1964 (Kush et al. 1987). Two stands had been regenerated naturally from mature longleaf pine by the shelterwood system, one in the 1945-1950 period and the other in the 1955-1960 period. Thinnings to maintain desired levels of basal area were begun on plots in each stand when they were about 15 years old. All plots in both stands were burned with a winter prescribed fire at approximately two- to three-year intervals. The burning regime was staggered so that not all plots were burned the same years. The current study selected eight plots in the older stand and six plots in the younger. Half of these plots in each stand had been maintained at a basal area of 90 sq ft/ac and half at 120 sq ft/ac.

The two stands are adjacent on similar sites. Soils were described at each plot, and are relatively uniform, varying from well-drained Troup fine sand to well-drained Benndale fine sandy loam, on gently rolling uplands with two to six percent slopes. Site index at base age 50 varied from 71 to 80, with a mean of 75, typical for longleaf on such sites. These ultisols are formed in deep, uniform beds of unconsolidated sands and sandy loams, and are acidic, low in nutrients, and often have excessive internal drainage.

Increment cores were extracted at breast height from two dominant trees on each plot. Sample trees were selected qualitatively as representative of healthy dominant crown classes, with average diameters of 12.3 in. and 10.8 in. for the 90 and 120 sq ft/ac basal areas in the older stand, and 8.9 in. and 7.8 in. for the two basal areas, respectively, in the younger stand. Cores were prepared for

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[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2/] Professor, Department of Forestry, Clemson University, Clemson, SC 29634-1003.

[3/] This research was supported by the Southern Forest Experiment Station, USDA Forest Service, New Orleans, LA.

measurement, cross-dated by visual inspection, and rings measured with a digital micrometer using standard techniques (Phipps 1985). Cross-dating for these short chronologies was aided by the occurrence of clearly defined signal years throughout all ring sequences. Thus, all tree-ring measurements were absolutely dated.

A simulation model was used to assess the impact of climate on the tree-ring sequences. The model calculates a drought index for southern pines (DISP), that estimates differences in annual growth increments due to favorable or unfavorable climate, just as site quality differences are estimated with site index. DISP makes use of both the timing and intensity of wet and dry periods during a current growing season, plus two years of preconditioning antecedent weather, to calculate departures from the long-term, or normal, pattern of radial growth. The model is more fully explained elsewhere in this volume (Zahner and Saucier 1988) and in Zahner and Grier (1988). DISP values were calculated for each year from 1964 through 1985 for the EEF in the Alabama Coastal Plain (fig. 1, table 1) from data provided by the National Weather Service (NOAA 1988).

Average ring width for each year of the respective tree-ring sequences for each plot was calculated from the ring-width measurements of individual cores, and plotted over calendar years for each plot (fig. 2). Juvenile wood was eliminated by using ring measurements at age 15 years and older. As clearly evident in the two examples in figure 2, ring-width sequences in these short-term, relatively young tree chronologies exhibit strong exponential decay curves with increasing age, indicated by the "adjusted trends" in the figure. Beginning with the age of the most recent complete annual ring, 1985, a time series for tree age was established for each plot, back to age 15 years. In the model that follows, tree age is recognized as the single intrinsic factor with the greatest effect on ring width (Fritts and Swetnam 1988); therefore, in analyzing the impacts of environmental factors, it was possible to compare tree rings from trees of equal age.

The analysis used in this study is a modification of a linear aggregate model for the potential components of tree-ring variation in young evenaged stands of southern pine (Zahner 1988). The dependent variable, RW_t, representing a ring-width measurement accurately dated to calendar year t, is modeled as the aggregate of seven basic components of the equation:

$$RW_t = f(AGE_t, SITE_t, BASAL\ AREA_t, CLIMATE_t, BURN_t, STAND_t, ERROR_t)$$

where:

AGE = The age related growth trend in year t that is shared by all dominant longleaf pine trees in a given plot. This trend is the ring-width decay curve associated with increasing age that arises from the geometrical constraint of adding rings to stems of increasing diameter. This trend was modeled with a reciprocal function of tree age by individual plots.

SITE = Independent site-related growth variation, reflecting the edaphic characteristics of soil, topography, and geology that regulate productivity for the given plot, a constant for all t years. Site index for each plot was used as the measure of this variable.

BASAL AREA = The effect of stand density, or competition among individual trees, acting on sample trees in year t. This component was measured by the two levels of basal area, 90 and 120 sq ft/ac, maintained relatively constant for all t years within a given plot.

CLIMATE = The climatically-related growth variations common to the given stand of trees in year t, including current weather, preconditioning climate, and the interaction of climate with site. The rainfall and temperature patterns of each growing season were modeled with the DISP simulation, as described above.

BURN = The exogenous disturbance pulse in year t, originating from forces outside the given stand, resulting from the effect of prescribed fire on the growth of sample trees. A dummy variable, indicating burn or no burn in the winter prior to growing season t, was used as an independent variable for each plot.

STAND = The sum of intrinsic factors unique to each stand, operating over the history of the stand up to year t, but not measurable directly. A dummy variable indicating the older or younger stand was used as an independent variable for each plot.

ERROR = The random variance in ring width in year t due to unmeasured and mis-measured growth-influencing factors, both endogenous and exogenous, not represented by the above six measured components.

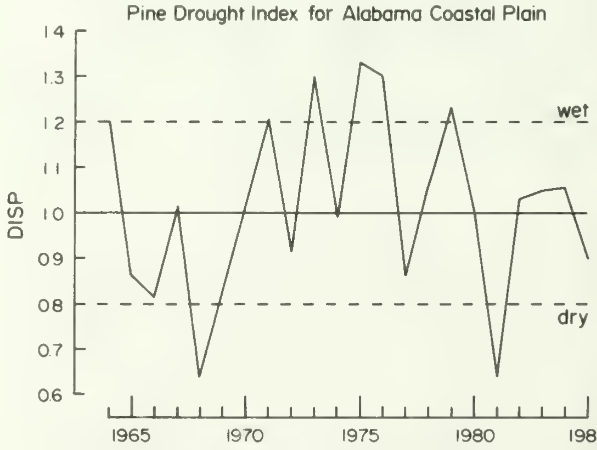

Figure 1.--DISP values (Alabama Coastal Plain) plotted over calendar years for the period 1964-1985. Values greater than 1.2 are substantially more favorable than average for pine growth, and values less than 0.8 are substantially less favorable than average for pine growth.

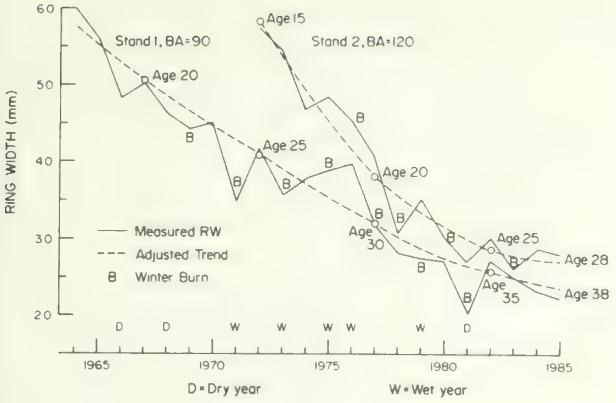

Figure 2.--Examples of tree-ring time series for two plots: One in stand 1 and one in stand 2. The dashed trend lines represent the approximate ring-width decay curves due to increasing age.

Multiple regression analysis was used to test the significance of each component in the aggregate model as an appropriate technique to fit the measured field and laboratory data to a time trend (Draper and Smith 1966). The examples in figure 2 indicate burn and no burn years for each of two plots only, one in each stand, and do not show burn and no burn years for the other 12 plots. The figure also denotes the unusually wet (1971, 1973, 1975, 1976, and 1979) and unusually dry (1968 and 1981) years that comprise the major climatic impacts on all plots.

RESULTS AND DISCUSSION

The multiple regression analysis resulted in the following relationship, in which all independent variables are highly significant (table 2), with an $R^2 = .82$:

$$\text{(1)} \quad RW = 0.002 + 91.0\,(1/\text{Age}) - 0.439\,(\text{Burn vs No Burn}) + 1.264\,(\text{DISP}) - 0.01139\,(\text{Basal Area}) - 0.588\,(\text{Stand 1 vs Stand 2})$$

Site index was not a significant variable in the model. As noted above, the variation in site quality was not great from plot to plot.

After the effect of age was fixed in the model, prescribed winter burning, climate (measured by DISP), and stand density (measured by basal area) were all nearly equal in their respective reductions to sequential R^2. The effect of stand 1 vs stand 2 was purposely entered last, after the three measureable factors were fixed.

The effect of stand density on ring widths is approximately as expected for growth per tree in young, evenaged longleaf pine stands in the Gulf Coastal Plain. Although only two levels of basal area were sampled, ring widths reflecting the decrease from 120 to 90 sq ft/ac, maintained in both stands from age 15 years to 1985, are consistent for the sites and ages encountered. Average ring widths for trees between 20 and 28 years of age, for example, were about 9 percent per year greater with the lower stand densities.

Table 1.--Annual DISP values calculated for the Alabama Coastal Plain climatic division for the period 1964-1985.

Year	DISP Value	Climate - Growth Impact Rating
1964	1.199	Growth moderately greater than average
1965	0.847	Growth moderately less than average
1966	0.806	Growth moderately less than average
1967	1.007	Average growth (+ or - 10%)
1968	0.664	Growth substantially less than average
1969	0.828	Growth moderately less than average
1970	1.022	Average growth (+ or - 10%)
1971	1.206	Growth substantially greater than average
1972	0.924	Average growth (+ or - 10%)
1973	1.297	Growth substantially greater than average
1974	0.988	Average growth (+ or - 10%)
1975	1.330	Growth potential maximum
1976	1.292	Growth substantially greater than average
1977	0.861	Growth moderately less than average
1978	1.061	Average growth (+ or - 10%)
1979	1.230	Growth substantially greater than average
1980	1.003	Average growth (+ or - 10%)
1981	0.658	Growth substantially less than average
1982	1.033	Average growth (+ or - 10%)
1983	1.051	Average growth (+ or - 10%)
1984	1.061	Average growth (+ or - 10%)
1985	0.896	Growth moderately less than average
22-yr ave	1.012	Average growth (+ or - 10%)

Table 2.--Statistics for regression equation (1). Variables listed in order of entering analysis (prescribed, not stepwise). Constant = 0.002

Variable	Coefficient	Standard Error	Prob. b = 0	Sequential R^2
1/Age	91.025	3.218	0.000	.66
Basal Area	- 0.01139	0.00193	0.000	.69
Winter Burn	- 0.4387	0.0672	0.000	.72
DISP (climate)	1.2637	0.1575	0.000	.77
Stands 1 vs 2	- 0.5881	0.0681	0.000	.82

With age fixed at 25 years and basal area at 100 sq ft/ac, the model finds that average ring widths in both stands are reduced about 13 percent by previous winter burns during years of normal climate. Winter burns coinciding with summer drought reduce average ring widths by as much as 28 percent. The negative effect of winter burning is nullified when the burn is followed by a growing season with favorable climate.

Boyer (1987) reports basal area growth of young longleaf pine in similar natural stands on the EEF was reduced 18 percent by biennial prescribed winter burns over a period of 10 years. Crown scorch with these low intensity fires is considered minimal, and the cause of reduced growth associated with biennial prescribed burns is not known.

Ring widths during years without winter burns, in both stands at age 25 years and basal areas of 100 sq ft/ac, are reduced about 15 percent by moderate summer droughts and are increased about 12 percent by favorable summer weather. Severe droughts occurred twice, in 1968 when stand 1 was 21 years old and stand 2 was still in its juvenile stage, and in 1981 when stand 1 was 34 years old and stand 2 was 24 years old. The exceptionally favorable climate of the 9-year period 1971 through 1979 occurred when stand 1 was aged 24-32 years old and stand 2 was aged 14-22 years old. Responses of tree-ring widths to these climate extremes in the two stands can be compared only at equivalent ages, applying the regression model.

The sequences of wet and dry years leading up to the years when each of the two stands was 25 years old were quite different. Age 25 for stand 1, 1972, was preconditioned by a wet year, whereas age 25 for stand 2, 1982, was preconditioned by a dry year. Both stands, however, for the 10-year periods that they were aged 19 to 28 years, respectively, experienced identical average climatic growing conditions.

The regression coefficient for the variable stand 1 vs 2 indicates that, for all ages, both basal areas, both burning regimes, and all climatic conditions sampled, trees in stand 2 had tree rings that averaged .59 mm smaller than trees in stand 1. At age 25 years, basal area at 100 sq ft/ac, under normal climate, and with no winter burn, this difference amounts to 17 percent narrower ring widths. This difference could be due to any of a number of factors: (1) different intrinsic past histories, such as juvenile stocking and early stand development; (2) different climate patterns, such as dry and wet sequences prior to given ages; (3) different winter burning schedules prior to given ages; and (4) unidentified differences in climate or site between the two time periods, such as changing atmospheric pollution stress. This study is far too limited in scope to separate these possible causes.

CONCLUSION

The results of this study find no unexpected relationships between tree growth and environmental factors known to affect tree rings. The sample, adequate for quantifying the two stands studied, is too small to permit more than a general application of results to similar stands of longleaf pine in the Gulf Coast region. Perhaps the most significant finding is the confirmation that prescribed winter burning reduces growth in these young stands, and that current weather conditions can intensify or ameliorate this effect of fire.

The tree-ring analysis finds three factors affecting annual ring widths of trees sampled in the two stands of natural longleaf pine on the EEF:

1. For the range in stand density sampled, limited to two basal areas in each stand, a maintained reduction in basal area from 120 to 90 sq ft/ac results in about a 9 percent sustained increase in ring widths for trees in stands 20 to 28 years old.

2. Prescribed winter burns result in a 13 percent decrease in ring widths the season following burning, for trees in stands between 20 and 28 years of age. This reduction in ring widths is 28 percent when coinciding with drought years and is nullified when coinciding with years of unusually favorable weather.

3. Favorable and unfavorable summer weather conditions increase and decrease ring widths by 12 percent and 15 percent, respectively, for trees in stands between 20 and 28 years old with basal areas of 100 sq ft/ac.

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THIRTY-YEAR DEVELOPMENT OF LOBLOLLY PINE STANDS AT VARIOUS DENSITIES[1]

Suzanne Wiley and Boris Zeide[2]

Abstract.--In 1970 forty plots were established in a typical loblolly pine (Pinus taeda L.) plantation located in southeastern Arkansas. The study was designed to investigate the effects of thinning and crown shortening on volume growth. Plots have been periodically measured and the seventh inventory of this stand was completed in 1988 as trees reached their thirtieth year. At this inventory, the current annual diameter growth increment at the lowest density (30 square feet/acre) was twice that at the highest density (90 square feet/acre). Accumulated cubic foot volume and maximum mean annual increment increased with density and generally with crown ratio. The maximum accumulated total stem volume and mean annual increment were produced by treatments at the highest density with light pruning (crown ratio of 55% of total tree height). Maximum accumulated merchantable board-foot volume occurred in plots maintained at 70 square feet of basal area with light pruning.[3]

INTRODUCTION

In 1970 the Southern Forest Experiment Station established forty experimental plots in a typical 12 year old loblolly pine plantation located in southeastern Arkansas (Burton 1968, 1971). This study was designed to evaluate the effects of various thinning and crown shortening treatments on volume growth. Since 1981 the study has been conducted by the Department of Forest Resources of the University of Arkansas at Monticello in cooperation with the Forest Service and Georgia-Pacific Corporation. The present study plan (Zeide 1985) is a continuation of the previous work and provides for maintenance and periodic measurement of the plots. In 1987 the seventh remeasurement of the thirty year old trees was undertaken.

The original study design includes four levels of thinning and three levels of crown shortening. Each combination has three replications within a randomized complete block design. Four additional plots were established as check plots to represent each of the four thinning treatments without crown shortening. Each plot has a gross size of 132 by 132 feet and contains an inner plot 66 by 66 feet where all trees are individually identified with numbers. Thus, the 0.1 acre measurement plot is surrounded by a similarly treated 0.3 acre buffer zone one-half chain wide.

Plots were initially thinned at age 12, to 40, 60, 80 and 100 square feet of basal area per acre and crowns were pruned to 25, 40 and 55 percent of the total tree height. After the second inventory at age 15, basal areas were reduced to 30, 50, 70 and 90 square feet where they have been maintained. A salvage cutting was made after a severe ice storm at age 16 and plots were thinned again at ages 24, 27 and 30. Trees were pruned only twice at age 12 and 15. In 1984 five control plots were established in the adjacent untreated part of the plantation (Zeide and Leduc 1985).

During the winters of 1974 and 1979 severe ice storms caused extensive damage to the test (Burton 1981). Trees of three plots were so heavily damaged that their basal area was reduced and still remains below their intended treatments. Therefore these plots have been eliminated from the analysis.

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[3] We wish to thank Daniel J. Leduc for sharing the knowledge gained through his past experience with this study. We greatly appreciate his guidance and advice on procedures throughout its entirety. This investigation was funded in part by the U. S. Forest Service.

METHODS

Inventory Methods

The methods used to collect inventory data were basically the same as those used in previous inventories. The diameter at breast height (DBH) of each tree in the buffer strip was taken, basal area was calculated, and thinning was planned to maintain the same treatment level as the corresponding inner plot. On all inner plot trees diameters were measured at 1 foot, 3 feet, 4.5 feet (DBH) and at crown base. The crown radius was measured in the longest direction and 90 degrees to it. Heights were determined to the base of the live crown, to the top of the tree and to the even diameters of the stem required to calculate volume by the Grosenbaugh height accumulation method (Grosenbaugh 1954). Measurements of height and upper stem diameters were done using a Zeiss Teledendrometer, while lower diameters were measured with a diameter tape or caliper. In order to improve measurement accuracy, the dendrometer was calibrated for instrument bias and the correction was applied to all height data.

Selection Of Trees To Be Thinned

After calculation of the basal area of each measurement plot and its corresponding buffer area, thinning was planned to reduce each plot to the basal area prescribed by the study plan. Trees were thinned from below based on the following, somewhat overlapping, criteria (in order of decreasing importance): diameter at breast height, current annual diameter growth increment, form, height, spatial distribution and cone production.

Measurements of Felled Trees

In 1988 the 45 trees thinned from inner plots were measured in greater detail. Stump height, height to the first live branch, and total height were measured with a tape. The diameters outside bark (DOB) and corresponding diameters inside bark (DIB) were measured with a caliper every foot up to 8 feet, every 2 feet up to 34 feet and every 4 feet to the top of the tree. This information was used to calculate a correction factor which was used to adjust teletop heights as well as calculate the DIB/DOB ratio used with height accumulation to determine volume inside bark. Samples were cut from trees representing each treatment and used to determine the specific gravity of wood at various treatment levels and heights.

Methods of Data Treatment

Data Summarization. -- The SAS statistical package was used along with several Fortran programs to analyze the accumulated data for all seven inventories. Data were summarized by plot, density and pruning treatments. The current annual diameter growth increment (present DBH - previous DBH / number of years between inventories), basal area and volume were determined for each tree. Quadratic mean diameter, basal area, average total height, average crown ratio, and five volumes (three cubic foot and two merchantable volumes) were calculated for each plot and treatment. Present volumes and accumulated volumes, that is, present volume plus the sum of all previously thinned volume, were determined at each inventory. For the purposes of this paper, only total cubic foot volume and International 1/4-inch volume are discussed.

Volume Calculation. -- Using the Grosenbaugh (1954) technique, the volume of all inner plot trees was calculated as a linear function of height, the sum of the heights to each successive two inch taper step, and the accumulation of the previous sum to the upper two inch taper step. The form of this function as illustrated by Leduc and Zeide (1987) is:

$$VOLUME = A(H')+B(H)+C(L) \qquad (1)$$

where:
VOLUME is volume in any unit; A, B, and C are calculated coefficients; L is the sum of section lengths or tree height; H is the sum of the heights to the top of each section; and H' is the sum of the sum of the heights to each section.

The coefficients are based on the volume units, the size of the taper step, and the ratio of the diameter inside bark (DIB) to diameter outside bark (DOB) when inside bark volume is desired. The DIB/DOB ratio was obtained from the 45 tree sample. In addition to these coefficients, the program used to calculate volume based on height accumulation allows entry of a minimum DBH and top diameter for each volume calculated. The coefficients for equation 1 and the diameters used to calculate total cubic foot outside bark and International 1/4-inch volume are presented in table 1.

Table 1.--Diameter inside bark/diameter outside bark ratios, coefficients of equation (1) and diameters used to calculate volume by the height accumulation method.

Variables	Total cu ft Volume O.B.	International 1/4-Inch Volume
DIB/DOB ratio	1	0.9154
Coefficient A	0.0436	0.3325
Coefficient B	0.0000	-0.3380
Coefficient C	0.0073	-0.0714
Minimum DBH	0	9.6
Top Diameter	0	8.0

During the last three measurements, all study plot trees were measured with sufficient detail to calculate volume. However, the four previous inventories obtained detailed information for only 12 trees per plot. Only diameters were recorded for the remaining inner plot trees. In order to provide a comprehensive summary of volume growth, total cubic foot volumes predicted for these trees by Zeide and Leduc (1985) were used in this analysis. The same method described by Leduc and Zeide (1987) was used to predict International 1/4-inch volume for plot trees which had only diameter measurements in the first four inventories.

Analysis of Variance. -- Total height, diameter and accumulated stand volume were studied as functions of blocking, thinning, pruning and the thinning-pruning interaction. The effects of these treatments on height, diameter and both total cubic foot and merchantable volume growth were determined using the general linear models procedure of the SAS statistics package. In addition, least squares difference and Duncan's multiple range tests were used to determine where significant differences occurred.

Mean Annual Increment and Its Culmination. -- The accumulated total stem volume and accumulated International 1/4-inch volume for each plot at each inventory age was calculated using the sum of the present volume plus the volume removed by all previous thinnings. Rotation age and maximum mean annual increment were predicted at each density for both types of volume. The age at which MAI culminates was determined with the technique used by Leduc and Zeide (1987) based on the following model:

$$Y = Ae^{B/t} \qquad (2)$$

where:
Y = yield at time t; t = age of yield data;
e = the base of the natural logarithm, and A and B are estimated coefficients.

Using this equation, the age of culmination for mean annual increment is simply $-B$. This equation was fitted using the NLIN procedure in SAS. The resulting age of maximum MAI was used to calculate the expected mean annual increment at this age.

RESULTS

Current Annual Increment of Diameter

As expected, diameter growth per tree and thus, basal area increase, is greatest on the most heavily thinned plots and decreases with increasing density. Table 2 illustrates the changes in current annual growth increment of diameter at breast height in inches per year for each inventory period by density treatment. The lowest period of diameter growth for all treatments was between the ages of 19 and 24. This slowed growth can probably be related to the extreme drought conditions of several summers during this period. During the past three years, the current annual diameter growth of trees in plots maintained at 30 square feet of basal area was almost twice that of trees at 90 square feet, and more than three times that of trees in control plots at 144 square feet.

Table 2.--Current annual growth increment of diameter at breast height by density level for each inventory period. (inches/year/tree)

Age	Basal Area	(Sq Ft/Acre)				Control
Years	30	50	70	90	Mean	144
12-15	.60	.45	.33	.25	.37	.
15-19	.64	.55	.44	.37	.46	.
19-24	.44	.35	.28	.23	.30	.
24-27	.56	.45	.40	.31	.39	.
27-30	.61	.45	.40	.33	.40	.17
12-30	.57	.45	.37	.30		

Evaluation of Stand Variables

Significant differences at the 0.05 level were demonstrated by stand variables (diameter at breast height, total height and crown ratio) as a function of thinning, but no differences were observed among these variables within pruning treatments. Table 3 illustrates the current quadratic mean diameter, mean total height and live crown ratio before thinning at each density. The mean DBH at each density level is significantly greater than that of the next higher density, resulting in five significantly different groups. Duncan's multiple range test indicates that trees in plots maintained at all treatment levels are significantly taller than those of control plots, but height is not significantly different between treatments. The percent of live crown to total tree height (crown ratio) increases with decreasing density. Plots with basal areas of 30 and 50 square feet consist of trees with crown ratios significantly greater than all other treatments. The crown ratios at 70 and 90 square feet of basal area are not significantly different from each other, but are significantly higher than control plots.

Table 3.--Stand variables (quadratic mean diameter, total height and live crown ratio) before thinning at 30 years of age by density.

Basal Area	N Plots	N Trees	DBH	Total Height	Crown Ratio
30	10	23	17.8	72.4	58
50	10	42	16.3	75.0	53
70	9	64	14.6	73.9	49
90	8	87	13.3	72.2	47
144 Ctrl	5	123	10.4	62.0	42

Accumulated Total Stem Volume

At each inventory accumulated total stem volume in cubic feet per acre increased with increasing density (table 4). The control plots, not established until the sixth inventory, currently have a mean basal area of 144 square feet/acre and volume slightly less than the accumulated volume of plots thinned to 30 square feet. A regression analysis of the accumulated total stem volume data by inventory shows that the effects of density are significant at the 0.05 level for every period. Plots maintained at 30 square feet/acre have always produced significantly less total stem volume than all other treatments. Since age 16 basal areas of 70 and 90 square feet/acre have produced significantly higher total stem volumes than all other treatments, but have not been significantly different from each other.

Table 4.--Accumulated total stem volume outside bark (present volume plus all previously removed volume) in cubic feet per acre by density at each inventory.

Basal	N	Age in Years					
Area	Plots	15	16	19	24	27	30
30	10	2664	2773	3227	3947	4252	4619
50	10	2815	2984	3635	4634	5024	5540
70	9	2878	3111	3915	5091	5571	6304
90	8	2921	3166	4026	5198	5813	6604
144 Ctrl	5	.	.	.	.	3604	4516

The effects of pruning are also significant at the 0.05 level. The most obvious trend represented by the total stem volume data is that volume increases with both basal area and percent of live crown as is demonstrated by the 1987 data (table 5). Since age 15 light pruning, which reduced the live crown to 55% of total tree height, has produced the highest accumulated total stem volume. Since age 19 heavy pruning (crown ratio of 25%) has resulted in total stem volume which was significantly lower than all other treatments. Light pruning resulted in slightly higher volumes than no pruning, although these treatments are not significantly different.

Table 5.--Accumulated total stem volume outside bark (present volume plus all previously removed volume) in cubic feet per acre by density and pruning treatment at 30 years of age.

Basal	Percent of Live Crown			No
Area	25	40	55	Pruning
30	4285	4758	4715	4915
50	5078	5632	5948	5425
70	5790	6415	6495	6425
90	6335	6258	7008	6695
144 Ctrl	.	.	.	4516

Culmination of MAI for Total Stem Volume

The mean annual increment, in this case, the accumulated cubic foot volume divided by the age of the stand, provides a method of comparing the growth rates of different stands at a given point in time. The maximum mean annual increment of accumulated total stem volume and the age at which it occurs increase with increasing density (fig. 1). As basal area increases, the age of culmination of mean annual increment increases from 17 to 25 years. The age at which maximum mean annual increment occurs for each pruning level within each density treatment increases with increasing density and generally with decreasing pruning (fig. 2). Light pruning produced the greatest volume at all density levels except at 30 square feet/acre where no pruning produced the highest volume.

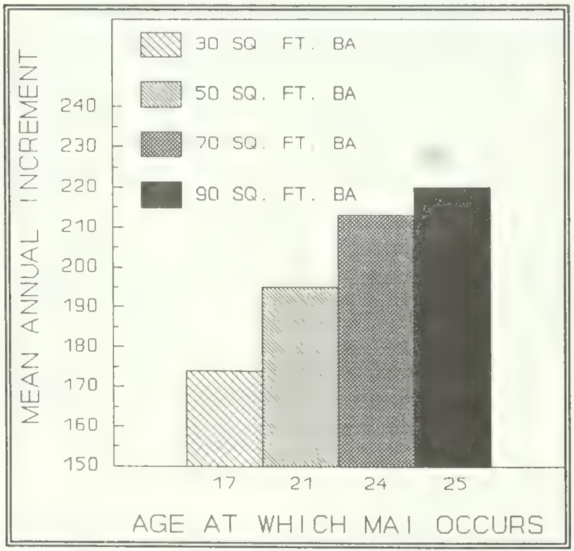

Figure 1.--Maximum annual increment of total stem volume and the age at which it occurs for each basal (BA) in square feet per acre.

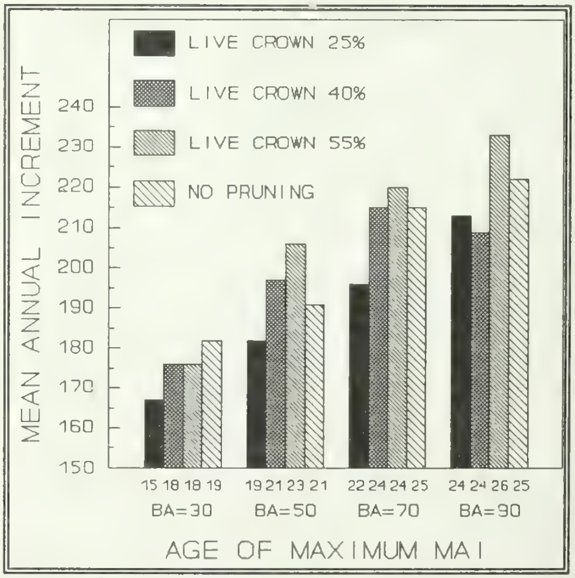

Figure 2.--Maximum annual increment of total stem volume and the age at which it occurs for each crown ratio and basal area (BA) in square feet per acre.

Accumulated International 1/4-Inch Volume

The purpose of this study is not to determine the effects of various thinning and pruning treatments on pulpwood, but rather, to evaluate their effects on sawtimber. Accumulated International 1/4-inch board foot volume increase (present merchantable volume plus all removed merchantable volume) over the 30 year period is somewhat different than that of total stem volume (table 6). At age 15 and 16 the highest volumes were produced by plots thinned to 30 square feet of basal area/acre. However, at 19 years 50 square feet/acre produced more and since age 24, plots thinned to 70 square feet/acre have produced the most merchantable volume. Since age 24 heavy thinning (30 square feet/acre) has resulted in a significantly lower merchantable volume than that produced by other treatments. At ages 24 and 27 merchantable volumes produced by treatments at 50, 70 and 90 square feet/acre were not significantly different. At age 30 merchantable volumes produced at 70 and 90 square feet/acre where significantly better than that produced at 50 square feet/acre.

Table 6.--Accumulated International 1/4-inch volume (present volume plus all previously removed volume) in board feet per acre by density at each inventory.

Basal Area	N Plots	Age in Years 15	16	19	24	27	30
30	10	1373	2107	5317	10097	12131	13958
50	10	1204	2049	6762	13214	15875	18256
70	9	736	1213	5948	14244	17432	20857
90	8	371	754	4673	12970	17238	20653
144Ctrl	5	.	.	.	.	9700	14316

The 1987 inventory data reveal that the highest board foot volume is produced by maintaining a basal area of 70 square feet/acre with light pruning (table 7). As with total cubic foot volume, light pruning produced the greatest merchantable volume at all density levels except 30 square feet/acre, where no pruning produced the highest volume. Since age 19 heavy pruning (live crown to 25% of total height) has resulted in a significantly lower merchantable volume than other treatments.

Table 7.--Accumulated International 1/4-inch volume (present volume plus all previously removed volume) in board feet per acre by density and pruning treatment at age 30.

Basal Area	Percent of Live Crown 25	40	55	No Pruning
30	11388	15230	14190	17160
50	16193	18490	20263	17720
70	17075	21187	23060	20820
90	21530	19187	22140	19710
144 Ctrl	.	.	.	14316

Culmination of MAI for Merchantable Volume

The application of the technique described by Leduc and Zeide (1987) to predict the rotation age and mean annual increment for accumulated board foot volume provides only a very tentative answer at this point in stand development. Culmination of mean annual increment for plots maintained at 30 square feet/acre will occur at 59 years of age, for 50 square feet/acre at 61 years, for 70 square feet/acre at 72 years and for 90 square feet/acre at 78 years of age. The predicted maximum mean annual increment for treatments at 70 and 90 square feet/acre will be almost twice that at 30 years of age. However, the predicted maximum mean annual increment for treatments at 30 and 50 square feet/acre will be less than one half again as much as they are at 30 years.

DISCUSSION

Diameter growth per tree and thus, basal area increase, is greatest on heavily thinned plots and decreases with increasing density. The recent inventory revealed that the current annual diameter growth of trees from plots maintained at 30 square feet/acre is almost twice that of trees from plots maintained at 90 square feet and more than three and a half times that of trees from control plots. However, volume growth per unit area follows the opposite pattern with almost one and a half times as much total stem volume produced at 90 square feet of basal area as is produced at 30 square feet.

Significant differences were observed between treatments when diameter at breast height (DBH), total tree height and crown ratio were studied as functions of thinning, but were not seen between pruning treatments. The mean DBH at each density increases significantly with each decreasing density treatment. The quadratic mean diameter of trees at 30 square feet/acre is more than one and a half that of trees at 144 square feet/acre in the control plots. Trees in plots maintained at all treatment levels are significantly taller than those of control plots, but total height is not significantly different between treatments. The percent of live crown to total tree height (crown ratio) increases with increased thinning. The crown ratios of all treatments are significantly higher than that of control plots. The crown ratio of trees at 30 square feet/acre is 38% greater than trees in the control plots at 144 square feet/acre. The original pruning treatments reduced the live crown to 25, 40 and 55% of tree height and included an additional treatment with no pruning. The current crown ratios of pruning treatments are 49, 50, 50 and 51%, respectively. There is no significant difference between these treatments when crown ratio is studied as a function of pruning. However, these pruning treatments have had a significant effect on volume growth. Inadvertently, the ice storms of 1974 and 1979 contributed to our understanding of another aspect of the investigated treatments. It appears that heavy pruning makes trees more vulnerable to storms while thinning has the opposite effect. These preliminary conclusions are based on the fact that the storms inflicted the greatest damage on plots with high densities at maximum pruning. Two of the three plots which are yet to recover from glaze damage were thinned to 90 square feet of basal area (the third to 70 square feet). All were pruned to 25% of total tree height. Damage was thoroughly documented on an individual tree basis.

Accumulated total stem volume in cubic feet per acre increases with both basal area and pruning treatment with the exception of the unthinned control plots (at 144 square feet/acre) which produced lower volumes than plots at 30 square feet/acre. Plots maintained at 30 square feet/acre have produced significantly less total stem volume than all other treatments at each inventory period. Since age 19 heavily pruned treatments have resulted in total stem volume significantly lower than all other treatments. Light pruning resulted in slightly higher volumes than no pruning, although these treatments are not significantly different. The removal of lower, shaded branches which consume more photosyntethate than they produce can increase volume yield (Smith 1962). At all density levels except 30 square feet/acre, light pruning has resulted in the highest mean annual increment. Leduc and Zeide (1987) point out that this exception strengthens rather than contradicts this rule because, in the most heavily thinned plots, lower branches are not shaded, and therefore, growth is increased by their presence. The maximum mean annual increment has reached its culmination for total stem volume at each of the designated treatments. The age of culmination increases with increasing density and generally with decreasing pruning.

The ultimate goal of this test is, of course, to determine the rotation age of merchantable timber, not pulpwood, produced by the various thinning and pruning treatments and the effects of these treatments on the quality and quantity of the product. The treatments which produced the maximum amount of merchantable volume have changed throughout the history of the test. As expected, heavily thinned plots produced merchantable volumes earlier than dense plots. Since age 24 plots thinned to 70 square feet/acre have produced the most merchantable timber and heavy thinning (30 square feet/acre) has resulted in significantly lower volumes than that of all other treatments. As with total stem volume, light pruning produced the greatest merchantable volume at all density levels (except 30 square feet/acre, where no pruning was best) and heavy pruning resulted in significantly lower merchantable volumes. The culmination of mean annual increment is predicted to occur between 59 and 78 years for the various density treatments. In all cases, the prediction of mean annual increment forty years in the future is quite shaky. As the stand matures, a more reliable rotation age may be determined and the effects of thinning and pruning on merchantable volume can be better evaluated.

The seven inventories included in this study of the effects of thinning and pruning on the growth of loblolly pine have produced a wealth of data. The analysis thus far only represents a preliminary look at some of the growth factors involved. A complete analysis of all the data will help formulate a clearer picture of the development of planted loblolly pine stands and will facilitate their sensible management.

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STOCKING CONTROL MEASURES AFFECT

INDIVIDUAL PINE GROWTH AND DEVELOPMENT[1]

Terry R. Clason[2]

Abstract.--Precommercial and commercial thinning treatments were used to determine the influence of stocking control on crop tree growth and development. Precommercial thinning was used to achieve age 8 stocking of 1000, 600, 300, 200, and 100 TPA. Crop tree growth following commercial thinning at age 20 was inversely related to age 8 stocking rates.

INTRODUCTION

Once a pine plantation is established, intraspecific competition continually affects plantation growth and individual pine development. Craib (1939) investigated the effect of intraspecific competition on the growth of six pine species at 26 South African locations, which encompassed three site quality classes and three climatic regions. In 1947, Craib summarized the impact of intraspecific competition as follows: 1) neither species nor site quality influenced the age at which mutual competition among stand components of a give density commenced; even climate appeared to have no influence; 2) the degree of competition, measured by diameter growth reduction, is the same irrespective of species and site for a given age and stocking density; and 3) stand component diameter growth suppression commenced at 1,200 trees per acre (TPA) in the second year, at 600 TPA in the third year, at 400 TPA in the fourth year, at 300 TPA in the fifth year, at 200 TPA in the sixth year, at 150 TPA in the seventh year, at 100 TPA in the eight year, and at 50 TPA in the ninth year after planting. It was concluded for the species studied that thinning would be required to achieve maximum merchantable volume even when early stocking densities did not exceed 530 TPA on first and second quality sites and 300 TPA on third quality sites.

Foil _et al_. (1964) demonstrated the negative impact of excessive stocking on loblolly pine (_Pinus taeda_) growing at age 25 site index of 70 feet. By age 11, mean DBH of 400 dominant TPA was inversely related to early stocking density. Mean DBH on an initial 10 x 10 foot spacing exceeded the 6 x 6 foot spacing by 1.5 inches. In addition, DBH of 400 residual TPA on a precommercially thinned 6 x 6 foot spacing plot was 1.1 inches larger than the 400 dominant TPA on the unthinned plot.

Although loblolly pine plantations of similar age and composition can produce the same total cubic-foot wood volumes over a range of stocking density, the upper and lower limits of this range are not well defined. Diameter growth losses reported by Craib (1947) and Foil _et al_. (1964) suggest that the range of stocking densities narrows with increasing age and the upper limit of the range is of greater economic concern than the lower limit. Therefore, an optimum stocking density should fully utilize the site without limiting individual tree growth during a growing cycle of specified length. The foremost problem in optimizing stocking densities over time is recognizing the onset and degree of competition. Growth data from a 30-year-old loblolly pine thinning study will be used to determine whether numerical thinning schedules can optimize competition levels over time.

METHODS AND PROCEDURES

In 1958, a 20-acre experimental area was planted with loblolly pine seedlings at a spacing of 6 x 6 feet. Soils of the area were classified as eroded phases of the Shubuta and Cuthbert series, with an estimated site index for loblolly pine of 65 feet (25 year basis).

The experimental area had reverted from a cultivated field to a 40-year-old mixed pine-hardwood stand. Merchantable trees were harvested and remaining vegetation was piled and burned, 2 years before seedlings were planted.

After five growing seasons, 20 one-half acre plots were established and tree DBH and height were measured. Mean tree height was used to develop four replications of five plots. Five stocking densities, 1000, 600, 300, 200, and 100 TPA were randomly assigned within each replication. All plots in each replication were precommercially thinned, one to 1000 TPA and the remaining four plots to 600 TPA. Tree removal was based on spacing, tree quality, and indication of disease or insect attack.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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It was assumed that stand density would not effect DBH growth until competition between trees reached a significant level and that competition among trees at higher densities would begin at an earlier age than comparable trees at lower densities. The guideline Craib (1947) used to compare competition levels between two stocking densities was that a reduction in mean DBH growth of 0.1 inch at a higher density would precede any measurable competition at a lower density.

The DBH frequency distribution for the 600 TPA plots was used to select comparison trees on the 1000 TPA plots that possessed same DBH, range, and general distribution. Subsequently, DBH measurements to the nearest 0.01 inch were taken four times annually and used to compare mean DBH growth between the two densities. When DBH growth on the 600 TPA plots exceeded the 1000 TPA plots by 0.1 inch, three of the four 600 TPA plots in each replication were thinned to 300 TPA. The same procedures were used to establish the 200 and 100 TPA plots. The precommercial thinning, which proceeded in a step-wise manner toward lower densities as tree age and size increased, was completed by age 8. Periodic DBH and height measurements were taken between ages 8 and 20.

Two commercial thinning treatments, a two-phase (TPT) and a single-phase (SPT), were app2lied to each density treatment in a split-plot manner at age 20. TPT treatment reduced the density on 1000, 600, 300, 200, and 100 TPA plots to 300, 300, 200, 100, and 50 TPA, respectively, while SPT treatment density was not altered. At age 25, density for both commercial thinning treatments was adjusted to 200, 200, 100, 50, and 50 TPA for the 1000, 600, 300, 200, and 100 TPA plots. Prior to thinning, the equivalent of 50 crop TPA were identified on each split-plot using DBH, tree form, and spatial position as selection criteria. Residual tree DBH and height measurements were taken at ages 20, 25, and 30.

RESULTS AND DISCUSSION

Plantation Growth

Precommercial thinning (PCT) treatments had a significant impact on early plantation growth (Table 1). By age 20, dominant tree height varied among treatments averaging 59, 56, 62, 62, and 56 ft. for the 1000, 600, 300, 200, and 100 TPA plots. Merchantable volume yields differed among treatments but differences were not linearly related to stocking density. Yield on the 300 TPA treatment was comparable to the 1000 TPA, but exceeded yields on the 600, 200, and 100 TPA treatments by 250, 700, and 950 ft^3/acre, respectively. Sawtimber production was inversely related to stocking density, averaging 40, 55, 2,980, 3,530, and 6,330 bd. ft. (doyle)/acre for 1000, 600, 300, 200, and 100 TPA.

The first harvest on the TPT treatment removed approximately 40 percent of the age 20 standing volume. Higher stocking densities, 1000 and 600 TPA, harvest volumes were exclusively pulpwood, averaging 17 and 15 cords/acre. A product mix of pulpwood and sawtimber was removed from the 300, 200 and 100 TPA plots with the respective pulpwood and sawtimber volumes being 15, 9, and 3 cords/acre and 1,000, 1,500, and 3,400 bd. ft./acre.

Mortality. Pine mortality differed among treatments during the 10-year growth period. Higher mortality rates were detected at the higher stocking densities (Table 1). Mortality rate on the 1000 and 600 TPA treatments exceeded the 300, 200, and 100 TPA treatments by 98 trees. SPT and TPT treatment mortality rates averaged 85 and 14 TPA between ages 20 and 30. Most of the mortality occurred on the SPT treated 1000 and 600 TPA plots between ages 20 and 25, and totaled 300 and 90 TPA, respectively.

Merchantable Wood Yields. Total wood growth between ages 20 and 30 was influenced by PCT and CT treatments (Table 1). Mean yield increase for the three lower PCT stocking densities exceeded the two higher densities by 102 ft^3/acre, while the TPT treated plots exceeded the SPT plots by 240 ft^3/acre. PCT treatment volume growth differed between ages 20 and 25 and was attributed to volume lost to pine mortality. TPT treatment growth rate was greater than SPT rate during both 5-year growing periods. Periodic annual increment (PAI) (Table 2) differed between CT treatments with TPT surpassing the SPT by 30 ft^3/acre during the 10-year growth period.

Sawtimber Yields. Sawtimber growth was inversely related to stocking density (Table 1). Between ages 20 and 30, total sawtimber production for the 300, 200, and 100 TPA plots averaged 2,775 bd. ft./acre more than the 1000 and 600 TPA plots. TPT treatment growth was 1,000 bd. ft./acre greater than SPT treatment. Ten-year sawtimber PAI differed among PCT and CT treatments with lower stocking densities having higher incremental values (Table 2). PAI for the PCT 300, 200, and 100 TPA stocking densities averaged 238 bd. ft./acre more than the higher PCT densities, while mean TPT PAI was 84 bd. ft./acre greater than the mean SPT PAI.

At age 30 the impact of early stocking density on plantation growth could still be distinguished, even after commercial thinning. Optimum plantation development was obtained from PCT 300 TPA treatment that was commercially thinned twice. This stocking control regime produced merchantable volume yields comparable to TPT 1000 TPA plots and sawtimber yields comparable TPT 200 TPA plots.

Individual Tree Growth

By age 20, individual tree growth varied significantly among PCT treatments (Table 3). Crop

Table 1. Commercial thinning treatment mean plantation growth parameters for ages 20, 25, and 30 by precommercial thinning treatments

Precommercial Thinning Treatment	Stocking Twice Thinned	Stocking Once Thinned	DBH Twice Thinned	DBH Once Thinned	Merchantable Volume[1] Twice Thinned	Merchantable Volume[1] Once Thinned	Sawtimber Volume[2] Twice Thinned	Sawtimber Volume[2] Once Thinned
TPA	TPA		Inches		Ft^3/Acre		Bd. Ft./Acre	
Age 20 Existing Stand								
1000	944	980	6.1	6.2	3,670	3,600	80	0
600	632	610	7.0	6.8	3,270	3,000	0	110
300	312	300	9.5	9.1	3,520	3,260	3,500	2,400
200	216	176	10.0	10.1	2,940	2,450	3,780	3,290
100	112	88	13.2	13.0	2,780	2,110	7,700	5,560
Age 20 Harvested Stand								
1000	480	0	5.7	0	1,450	0	80	0
600	304	0	6.4	0	1,270	0	0	0
300	160	0	9.0	0	1,630	0	1,020	0
200	104	0	9.5	0	1,290	0	1,570	0
100	48	0	13.3	0	1,210	0	7,700	0
Age 20 Residual Stand								
1000	384	980	7.3	6.2	2,200	3,600	80	0
600	328	610	7.5	6.8	2,000	3,000	0	110
300	152	300	9.9	9.1	1,940	3,260	2,700	2,400
200	112	176	10.5	10.1	1,650	2,450	3,700	3,290
100	64	88	13.1	13.0	1,570	2,110	4,300	5,560
Age 25 Existing Stand								
1000	368	680	8.2	6.7	2,900	3,640	880	680
600	312	520	8.1	7.7	2,310	3,460	260	420
300	144	280	11.0	10.0	2,410	3,740	3,980	4,140
200	216	168	11.6	11.1	2,120	2,930	4,250	5,520
100	64	80	15.0	14.3	2,050	2,330	7,120	7,510
Age 25 Harvested Stand								
1000	168	490	7.3	5.6	1,020	1,870	0	0
600	112	310	7.1	6.9	580	1,690	0	0
300	48	180	9.7	9.4	570	2,180	340	1,090
200	56	112	10.7	10.5	880	1,710	1,230	2,650
100	16	32	16.0	14.5	580	960	2,170	3,160
Age 25 Residual Stand								
1000	200	190	9.0	8.7	1,990	1,770	880	680
600	200	210	8.7	8.7	1,730	1,770	260	420
300	96	100	11.7	10.8	1,840	1,570	3,640	2,350
200	56	56	12.6	12.4	1,250	1,220	3,020	2,880
100	48	48	14.7	14.2	1,470	1,370	4,950	4,350
Age 30 Existing Stand								
1000	184	190	10.1	9.8	2,510	2,400	2,990	2,350
600	184	210	9.9	9.0	2,320	2,090	1,860	890
300	96	100	12.0	12.0	2,370	1,720	6,520	4,590
200	56	56	13.6	13.6	1,630	1,500	5,220	4,430
100	48	48	17.0	16.3	1,940	1,800	7,940	7,100

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[1] Merchantable volume to a 3-inch dib computed from (Clason and Cao, 1986).

[2] Sawtimber computed as cubic volume using (Clason and Cao, 1986) and converted to Bd. Ft. Doyle using (Williams and Hopkins, 1968).

tree DBH and height for the 1000, 600, 300, 200, and 100 TPA treatments averaged 8.9, 8.7, 10.8, 11.3, and 13.8 inches and 60, 58, 64, 64, and 57 feet, respectively. These data suggest that initial stocking density had a profound influence on individual tree growth, which would impact the economic potential of a loblolly pine plantation. The ideal stocking density upper limit at age 8 appeared to be less than 600 TPA but greater than 100 TPA while the age 20 the upper limit is approaching 100 TPA.

Mean DBH growth for the CT treatments between ages 20 and 30 differed with the TPT exceeding SPT by 0.1, 0.5, 1.2, 1.0, and 1.0 for the 1000, 600, 300, 200, and 100 TPA PCT treatments. CT growth differences detected at 100 TPA indicate that the optimum upper limit after age 20 should be less than 100 TPA.

Diameter Growth. PCT and CT treatments had a significant impact on crop tree DBH growth between ages 20 and 30 (Table 3). Mean DBH growth for the three lower PCT stocking densities was 2.6 inches, which exceeded the two higher densities by 18 percent. The TPT and SPT treatment growth averaged 2.7 and 2.0 inches. The most growth, 3.1 inches, occurred on the TPT PCT 100 TPA treatment. Similar growth responses were detected for both 5-year growing periods.

Height Growth. Height growth averaged 14 ft for both the PCT and CT treatments during the 10-year growth period (Table 3). The most growth, 18 ft, occurred on TPT and SPT treated 1000 TPA plots, while the TPT treated 100 TPA plots grew the least, 10 ft.

Basal Area Growth. PCT and CT stocking densities significantly influenced crop tree basal area growth between ages 20 and 30 (Table 3). Basal area growth on the two higher PCT stocking densities averaged 0.23 ft^2 per tree, which was 0.15 ft^2 less than the three lower densities. Failure to adjust stocking at age 20 reduced basal area growth on all PCT plots. SPT treatment tree growth averaged 0.25 ft^2, while TPT tree growth averaged 0.38 ft^2. The TPT treatment had an immediate and continuing impact on crop tree basal area growth. TPT crop tree growth following the first thinning surpassed the SPT trees by 60 percent between ages 20 and 25. After stocking density was reduced to similar levels at age 25, TPT tree growth exceeded SPT growth by 30 percent at age 30.

Merchantable Volume Growth. Merchantable volume yield measures the total impact of DBH and height growth on crop tree development. Volume growth differences among stocking densities were similar to basal area growth differences. Higher stocking densities either PCT or CT resulted in less crop tree growth (Table 3). By age 30, PCT treatment mean tree volumes were 9.8 and 14.6 ft^3 for the two high and three lower densities, while the TPT and SPT mean tree volumes were 14.1 and 11.6 ft^3, respectively. Since age 20, mean crop tree volume on the TPT and SPT treatments has increased 107 and 94 percent.

Sawtimber Growth. Sawtimber conversion factors developed by Williams and Hopkins (1968) were used to convert sawtimber volumes from ft^3 to Bd. Ft. (Doyle) (Table 3). Converted crop tree sawtimber volume differences reflect the impact of stocking density on the economic potential of a pine plantation. PCT mean tree sawtimber volumes differed among treatments. Mean tree volumes for two higher and three lower densities at age 30 were 26.3 and 101.1 Bd. Ft. Sawtimber growth on the SPT PCT treatments between ages 20 and 30 was 50 percent less than TPT PCT growth. Sawtimber growth response to CT was inversely related to PCT stocking rates. TPT growth averaged 40, 24, 70, 79, and 99 Bd. Ft. for 1000, 600, 300, 200, and 100 TPA; SPT growth averaged 31, 7, 38, 59, and 74 Bd. Ft. for 1000, 600, 300, 200, and 100 TPA.

Pine stocking density can have a profound impact on growth and development of a loblolly pine plantation. As a plantation ages, the stocking density range in which optimum growth is achieved narrows. Failure to lower the upper limit of this range will reduce total wood yields and future stand values.

CONCLUSION

Growth response of the selected crop trees to varying levels of stocking density indicates that plantation growth and economic development can be optimized when the upper limit for stocking density falls within the following ranges:

AGE	TPA
8 - 14	600 - 300
14 - 20	400 - 100
20 - 25	200 - 50
25 - 30	100 - 50

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Table 2. Commercial thinning treatment periodic annual growth increment for merchantable and sawtimber yields between ages 20 and 30 by precommercial thinning treatment

Precommercial Thinning Treatment	Age 20-25		Age 25-30		Age 20-30	
	Twice Thinned	Once Thinned	Twice Thinned	Once Thinned	Twice Thinned	Once Thinned
TPA						
	Merchantable Yield (Ft^3/Acre/Year)					
1000	136	8	126	126	131	67
600	62	92	118	64	90	78
300	94	96	106	32	100	64
200	94	96	78	56	86	76
100	96	44	94	86	95	65
	Sawtimber Yield (Bd. Ft./Acre/Year)					
1000	160	136	422	334	291	235
600	52	84	320	94	186	88
300	186	348	576	308	431	328
200	408	446	440	312	424	379
100	564	487	598	550	581	470

Table 3. Commercial thinning treatment mean crop tree growth parameters for ages 20, 25 and 30 by precommercial thinning treatment

Precommercial Thinning Treatment	Age 20-25		Age 25-30		Age 20-30	
	Twice Thinned	Once Thinned	Twice Thinned	Once Thinned	Twice Thinned	Once Thinned
TPA						
	DBH (Inches)					
1000	9.1	8.7	10.2	9.6	11.6	11.1
600	8.8	8.7	9.7	9.4	10.9	10.3
300	11.0	10.6	12.5	11.3	14.0	12.4
200	11.2	11.5	12.7	12.4	14.5	13.8
100	14.0	13.5	15.2	14.4	17.1	15.6
	Height (Feet)					
1000	59	61	71	71	77	79
600	57	59	66	65	71	69
300	65	64	71	71	79	78
200	64	63	70	71	77	76
100	58	56	63	65	68	71
	Basal Area (Ft^2)					
1000	0.45	0.42	0.57	0.51	0.74	0.67
600	0.42	0.43	0.52	0.49	0.65	0.58
300	0.66	0.61	0.85	0.84	1.08	0.83
200	0.69	0.72	0.88	0.84	1.15	1.04
100	1.08	1.00	1.27	1.14	1.61	1.34
	Merchantable Volume[1/] (Ft^3)					
1000	9.0	8.5	15.7	13.5	20.9	20.3
600	8.0	8.2	12.4	11.1	16.9	14.9
300	14.5	13.7	20.9	17.6	29.7	23.3
200	15.1	14.8	21.1	20.3	31.4	28.0
100	19.3	16.5	26.6	24.5	37.6	32.9
	Sawtimber[2/] (Bd. Ft.)					
1000	1.0	1.0	16.4	10.0	41.5	32.5
600	0.0	0.0	7.3	4.7	24.2	7.0
300	19.9	15.0	48.0	29.3	90.6	53.1
200	23.2	24.8	50.8	45.5	102.8	83.8
100	59.0	46.1	94.9	73.2	155.5	120.7

[1/] Merchantable volume to a 3-inch dib computed from (Clason and Cao, 1986).

[2/] Sawtimber computed as cubic volume using (Clason and Cao, 1986) and converted to Bd. Ft. Doyle using (Williams and Hopkins, 1968).

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EFFECT OF INTENSIVE CULTURE ON JUVENILE WOOD FORMATION AND WOOD PROPERTIES OF LOBLOLLY, SLASH, AND LONGLEAF PINE [1] [3]

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and
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Abstract.--Cultivation before and after planting plus fertilization 1 year after planting significantly increased diameter and height growth without reducing weighted average specific gravity of juvenile or mature wood of loblolly (Pinus taeda L.), slash (P. elliottii Engelm. var. elliottii), and longleaf pines (P. palustris Mill). At age 25, 24 years after fertilization, slash pine is outperforming longleaf and loblolly on control plots and contains only 33 percent of its basal area in juvenile wood. Longleaf and loblolly grew more than slash on the cultivation plus high fertilization plots but produced an average of 16 percent more juvenile wood.

INTRODUCTION

The adverse effects of juvenile wood on product quality and yield are of significant concern to southern pine growers and manufacturers. The industry needs to know the properties of the wood being grown and how silvicultural practices and genetic selection for wood quality influence these properties. Intensive site preparation, cultivation, and fertilization increase growth of southern pines but there are conflicting research results concerning the effect of these cultural practices on wood quality. There is a lack of information on how these cultural practices influence the growth pattern, proportion, and quality of juvenile wood of southern pines. Juvenile wood has lower specific gravity (SG) and shorter tracheids with thinner walls, larger fibril angles, and less alpha cellulose than mature wood (Thomas 1984). Pulp yields from juvenile wood are lower and building products containing juvenile wood are weaker (Senft and others 1985, Bendtsen and Senft 1986, Pearson and Gilmore 1980, Pearson 1988) and more prone to warp, creating problems for manufacturers and consumers (Quarles and Erickson 1987).

A radial cross-section of a pine stem contains three zones of wood (fig. 1): 1.) core or crown-formed wood produced by immature cambium in the vigorous crown, which has anatomical, chemical, and physical properties substantially different from mature wood; 2.) transition wood, which is in a zone where wood properties are changing rapidly before reaching maturity; and 3.) mature wood. In the spring, radial growth begins at the apex of the bole in the vigorous crown (Wareing 1958, Zahner 1963) thus, more thin-walled earlywood and a wider ring of earlywood are produced in the upper bole in the crown than in the lower bole. The transition to thick-walled latewood tracheids occurs first near the base of the bole, farthest from the source of auxins, and proceeds upward as the moisture stress increases and translocation of auxins down the bole decreases (Zahner 1963, Larson 1969). As trees grow older and taller and stands close, lower branches cease to be vigorous, and the lower portion of active crown moves up the stem. Therefore, there is a core of crown-formed wood surrounded by a band of transition wood from the butt to the merchantable top of the tree (Paul 1957, Zobel et al. 1959). Both crown-formed and transition wood are commonly referred to as juvenile wood.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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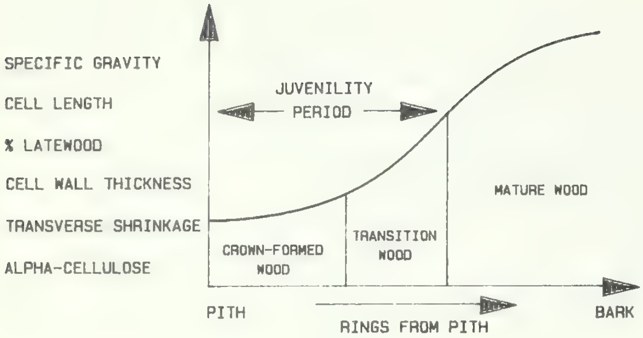

Figure 1.--Diagram of a radial cross section of a pine stem showing three zones of wood and how wood properties change with age (rings) from the pith.

In 1960 a study was established to determine the effects of cultivation and three levels of fertilization and selection for wood quality on growth and yield of loblolly (Pinus taeda L.), slash (P. elliottii), and longleaf pines (P. palustris). These plantings provided the opportunity to examine these treatment effects on juvenile wood formation and wood quality. The effects of intensive culture and genetic selection on growth and yield of southern pine from this study have been reported in several papers (Schmidtling and Amburgey 1977, Schmidtling 1973, Schmidtling 1984, Schmidtling 1987). Schmidtling (1973) reported that after 9 years' cultivation plus fertilization treatments greatly increased growth of all three species, with loblolly pines benefitting the most. At age 25, 24 years after fertilization, Schmidtling (1987) found the effects of intensive culture were still quite dramatic on all species, but the most important change was in the performance of longleaf pine compared to slash and loblolly. Height of longleaf was reported to be equal to slash and greater than loblolly on control plots. At the lowest levels of fertilization, height was equal for all species but at the highest levels of fertilization, loblolly grew best in diameter and height.

Our objective here was is to determine the effect of these intensive cultural practices and genetic selection for high SG on the formation of juvenile wood in loblolly, slash, and longleaf pines. The following questions were addressed:

1. How do intensive cultural practices and genetic selection for high SG influence the age at which loblolly, slash, and longleaf pines start producing mature wood?
2. How do intensive cultural practices and genetic selection for high SG affect the proportion and wood quality of juvenile and mature wood of loblolly, slash, and longleaf pines?

MATERIALS AND METHODS

The study plantation was established by the USDA Forest Service Southern Forest Experiment Station in 1960 on a Coastal Plain site in Harrison County near Gulfport, Mississippi. The study site had been stocked with second-growth longleaf pines that were clearcut in 1958-59. The site is on gently rolling land with slope ranging from 0 to 8 percent. The soils are well-drained upland, fine sandy loams in the Poarch series and the Saucier-Susquehanno complex. Soil samples taken at depths of 4 to 6 inches before planting averaged low in N (270 ppm), P (2-2.3 ppm P_2O_5) and K (43 ppm K_2O).

The plantation was established with open-pollinated seeds from parent trees with high specific gravity (HSG) and average specific gravity (ASG) for each of three species--slash, loblolly, and longleaf pines. Parent trees were chosen based on measurements made on increment cores, and trees were from natural stands located in southern Mississippi and southern Louisiana. The average increment core SG for the loblolly pine HSG progeny parents was 0.57 compared to 0.54 for the ASG progeny and for the longleaf pine 0.60 for the HSG progeny and 0.57 for the ASG progeny (Schmidtling 1973). The SG records for the slash pine parent trees are not available. The heritability of SG is substantial in southern pines (Zobel et al. 1959). The selection differential in this study was about 5 percent in the loblolly and longleaf, and unknown in the slash pine. Seeds from all parents within each population were mixed in equal proportions and sown in the nursery in 1959.

Stumps, soil, and competing vegetation were not disturbed on the control plots but cultivated plots were cleared of all stumps and slash and then plowed and disked.

In February and March 1960, the 1-year-old seedlings were bar-planted at 10x10-foot spacings. The design was a split plot with four replications. Main plots were species, and completely randomized within each main plot there were 10 subplots for 5 cultural treatments were applied to the HSG and 5 to the ASG seedlings. The cultural treatments were:

Abbreviation	Treatment
C	Control, no cultivation or fertilization
T-0	Cultivation with no fertilization
T-1	Cultivation and a single application of 1000 lbs 10-5-5 NPK/acre
T-2	Cultivation and a single application of 2000 lbs 10-5-5 NPK/acre
T-4	Cultivation and a single application of 4000 lbs 10-5-5 NPK/acre

Each subplot consisted of 100 trees (10 rows X 10 rows) surrounded by two border rows.

Cultivation consisted of disking three times each season for 3 years after planting and mowing in the fourth and fifth seasons. Fertilizer was distributed with an agricultural spreader and disked into the soil in May 1961, 1 year after planting.

In the winter of 1985, 25 years after planting, the d.b.h. and total height of all surviving measurement trees were recorded. Two increment cores, 10 mm in diameter were removed at breast height from each of 5 randomly selected trees from each subplot for a total of 20 trees per treatment x progeny combination and 200 trees per species.

In the laboratory one increment core from each tree was separated into 2-year segments from the pith to bark. The unextracted SG of each 2-year segment was determined based on green volume and ovendry weight. The second core from each tree was dried, glued into a slotted core holder, and surface-sanded. Thickness of earlywood and latewood were measured to the nearest 0.01 mm under a 65X microscope with a digitizing stage.

The age at which transition from juvenile to mature wood occurred was estimated to the nearest 2 years based on visual examination of plots of ring SG over rings from pith. Weighted specific gravities of the juvenile wood and mature wood zones were then determined by weighting segment SG by segment basal area for the rings included in the juvenile and mature zones. A split plot analysis of variance and Duncan's Multiple Range Test were performed on subplot means to examine the effects of cultural treatments and selection for high SG on the SG of juvenile, mature and all wood, the proportion of tree basal area in juvenile wood, and the d.b.h. and total height.

RESULTS AND DISCUSSION

The trees bored for juvenile wood analysis display the same dramatic increase in d.b.h. and height with increased cultural treatment (table 1) as Schmidtling (1987) reported for all trees on the plots. Mean d.b.h., averaged across species and seed sources, was 6.5 inches for the control, 6.4 inches for cultivation only, 8.1 inches for cultivation and low-level fertilization, 8.6 inches for cultivation and medium-level fertilization, and 9.1 inches for cultivation and high-level fertilization. On the control plots, longleaf trees were larger than the slash or loblolly. The three species varied little in d.b.h. or height on the low-level fertilizer plots, but the ASG loblolly were larger in diameter and taller than trees of other species on

Table 1--Average d.b.h. and total height by levels of intensive culture and species for trees with average and high specific gravity parents.

Species	Seed Source[1]	Treatment[2]				
		Control	Cultivation + No NPK	Cultivation + Low NPK	Cultivation + Med NPK	Cultivation + High NPK
				DBH (INCHES)		
LONGLEAF	ASG	7.3efghij[3]	6.1klm	8.1bcdefgh	8.8bc	8.6bcd
	HSG	6.8ijklm	6.2klm	7.5defghij	8.1bcdefg	9.1ab
SLASH	ASG	6.7ijklm	6.8hijkl	8.4bcdef	8.8bc	9.3ab
	HSG	6.6ijklm	7.0ghijkl	8.3bcdef	8.7bcd	9.0ab
LOBLOLLY	ASG	6.0klm	6.3jklm	8.9abc	9.3ab	10.1a
	HSG	5.5m	5.7lm	7.2fghijk	7.8defghi	8.5bcde
				TOTAL HEIGHT (FEET)		
LONGLEAF	ASG	55cdefg [3]	48gh	59bcde	60abcd	61abcd
	HSG	50fgh	49fgh	55cdefg	59bcde	62abc
SLASH	ASG	50fgh	53defg	59bcde	62abc	63abc
	HSG	51fgh	52efg	59bcde	60abcd	65ab
LOBLOLLY	ASG	40i	44hi	60abcd	62abc	68a
	HSG	39i	40i	49fgh	53defg	57bcdef

[1] ASG = Progeny of average specific gravity parents
HSG = Progeny of high specific gravity parents

[2] Low NPK = 1000 lbs 10-5-5 per acre
Med NPK = 2000 lbs 10-5-5 per acre
High NPK = 4000 lbs 10-5-5 per acre

[3] Values with the same letter do not differ at the 0.05 level according to Duncan's Multiple Range Test.

the high-level fertilizer plots. There was no significant difference in average d.b.h. or total height between ASG and HSG longleaf or slash, but ASG loblolly pines on the fertilized plots were significantly larger in d.b.h. and height than the HSG. The trees of all species on the cultivation plus high fertilization plots were significantly larger than the trees on the control or cultivated only plots.

Plottings of average specific gravity over rings from the pith (figs. 2 and 3) show that cultivation plus fertilization reduced annual ring SG of ASG and HSG longleaf and HSG slash during the first 8 to 10 years after fertilization and increased the duration of juvenility. Cultural treatments, however, had no significant influence on ring specific gravity or duration of juvenility of ASG or HSG loblolly or ASG slash.

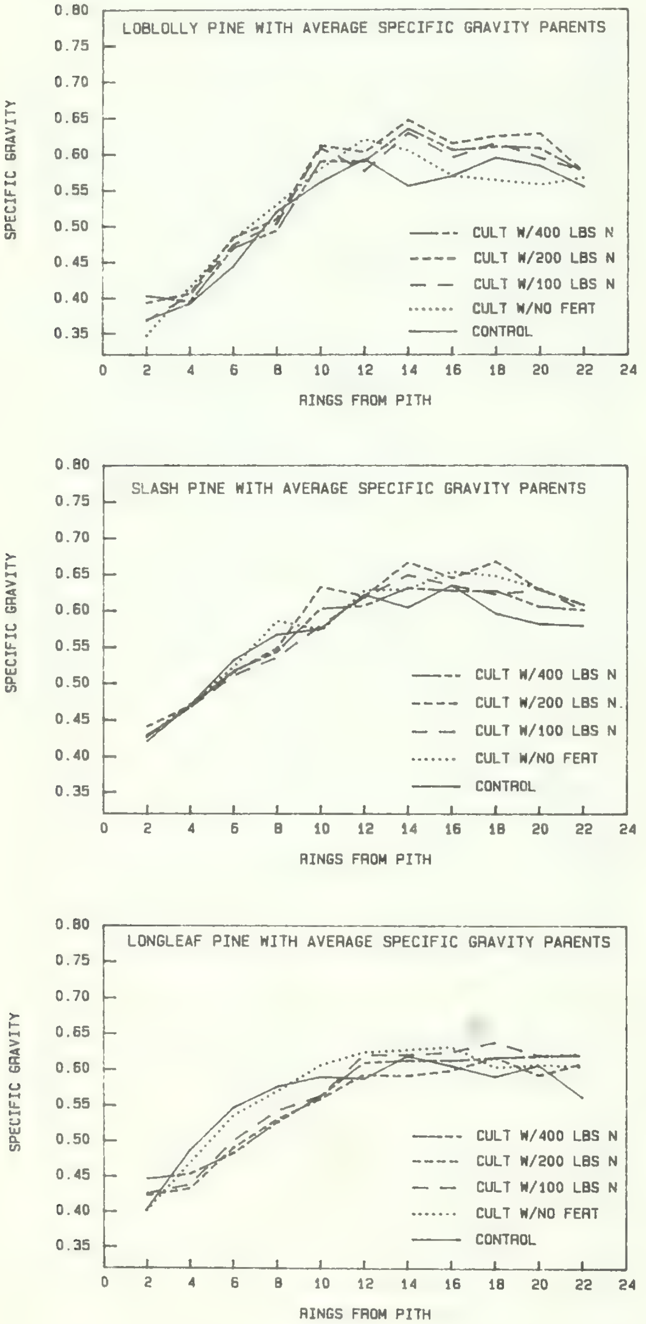

Figure 2.--Effect of intensive cultural treatment on ring specific gravity and length of juvenility for loblolly, slash, and longleaf pine average specific gravity progeny.

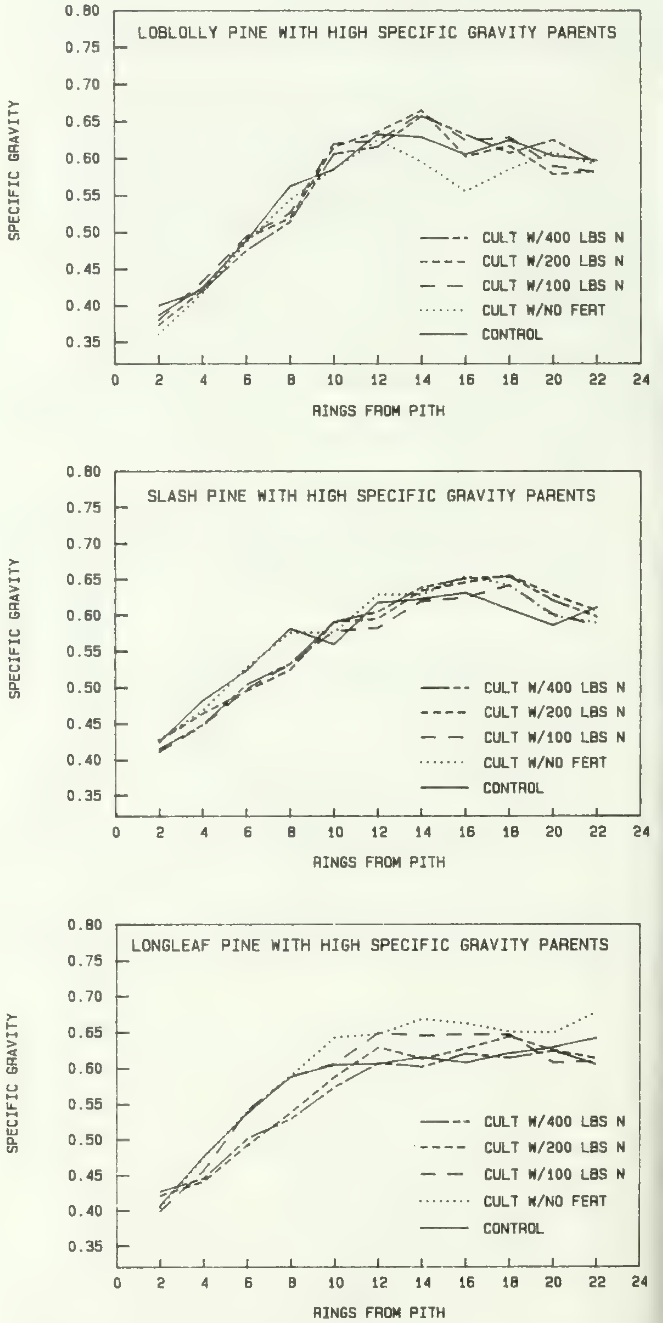

Figure 3.--Effect of intensive cultural treatment on ring specific gravity and length of juvenility for loblolly, slash, and longleaf pine high specific gravity progeny.

Based on figures 2 and 3, the duration of uvenility was estimated for each species:

pecies	Seed source	Treatment				
		C	T-0	T-1	T-2	T-4
		Number of rings in juvenile zone				
ongleaf	ASG	6	10	10	10	10
	HSG	6	8	10	10	10
lash	ASG	8	8	8	8	8
	HSG	6	6	8	8	8
oblolly	ASG	8	8	8	8	8
	HSG	8	8	8	8	8

Cultivation and cultivation plus fertilization did not significantly affect the average weighted SG of juvenile wood (table 2). Juvenile wood SG of loblolly was significantly lower than that of longleaf except for the HSG controls (table 2). Juvenile wood SG, averaged across cultural treatments and seed sources, was 0.45 for loblolly compared to 0.49 for slash and 0.51 for longleaf. The only significant difference between ASG and HSG progeny in juvenile wood SG occurred on the control and cultivated plus low fertilization loblolly plots and cultivation only slash plots.

Cultural treatments did not significantly reduce the SG of mature wood. There was no significant difference within a species and treatment between ASG and HSG progeny in mature wood SG except for the

Table 2--Average weighted specific gravity of juvenile, mature, and all wood by cultural treatment and species for trees with average and high specific gravity parents

Species	Seed Source[1]	Treatment[2]				
		Control	Cultivation + No NPK	Cultivation + Low NPK	Cultivation + Med NPK	Cultivation + High NPK
		JUVENILE WOOD SPECIFIC GRAVITY				
LONGLEAF	ASG	.50cdef [3]	.54a	.51abcd	.50cdef	.50cdef
	HSG	.49cdefg	.52abc	.53ab	.50cdef	.50cdef
SLASH	ASG	.51abcd	.51abcd	.49cdefg	.50cdef	.50cdef
	HSG	.49cdefg	.48efgh	.48efgh	.48efgh	.48efgh
LOBLOLLY	ASG	.44l	.46ijk	.44l	.45jkl	.44l
	HSG	.47ghij	.47ghij	.47ghij	.46ijk	.45jkl
		MATURE WOOD SPECIFIC GRAVITY				
LONGLEAF	ASG	.60bcde [3]	.62abcd	.62abcd	.60bcde	.62abcd
	HSG	.61bcd	.65a	.64ab	.62abcd	.61bcd
SLASH	ASG	.60bcde	.62abcd	.62abcd	.63abc	.62abcd
	HSG	.60bcde	.61bcd	.60bcde	.62abcd	.62abcd
LOBLOLLY	ASG	.58e	.59de	.60cde	.61bcd	.60bcde
	HSG	.61bcd	.60bcde	.62abcd	.62abcd	.62abcd
		ALL WOOD SPECIFIC GRAVITY				
LONGLEAF	ASG	.57abc [3]	.58ab	.56bcde	.55bcdef	.55bcdef
	HSG	.58ab	.60a	.58ab	.56bcde	.56bcde
SLASH	ASG	.57abc	.57abc	.56bcde	.57abc	.56bcde
	HSG	.57abc	.57abc	.55bcdef	.56bcde	.55bcdef
LOBLOLLY	ASG	.50i	.51hi	.51hi	.53fghi	.51hi
	HSG	.54defgh	.52hi	.53fghi	.51hi	.52ghi

[1] ASG = Progeny of average specific gravity parents
HSG = Progeny of high specific gravity parents

[2] Low NPK = 1000 lbs 10-5-5 per acre
Med NPK = 2000 lbs 10-5-5 per acre
High NPK = 4000 lbs 10-5-5 per acre

[3] For each type of wood, values followed by the same letter do not differ at the 0.05 level according to Duncan's Multiple Range Test.

loblolly control trees. Mature wood SG, averaged across cultural treatments and seed sources, was 0.61 for loblolly and slash and 0.62 for longleaf.

Specific gravity of juvenile and mature wood combined was significantly lower for loblolly pine than for slash or longleaf (table 2). SG of all wood, averaged across cultural treatments and seed sources, was 0.52 for loblolly, 0.56 for slash, and 0.57 for longleaf. These differences are due to differences in juvenile wood SG. There was no significant difference between the control and treatment trees in all wood weighted SG within a species and seed source. The only significant difference between HSG and ASG progeny in total weighted SG occurred in the loblolly control trees.

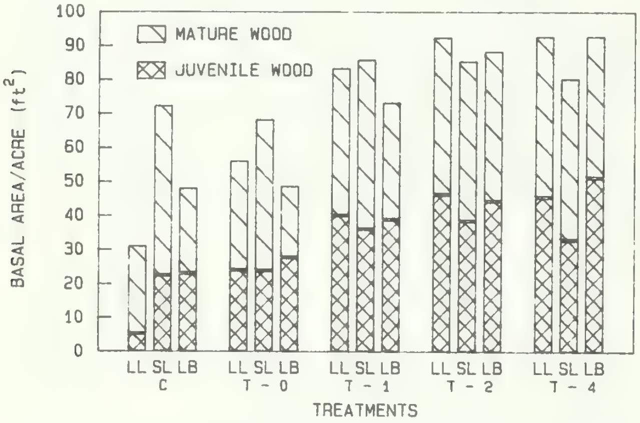

Figure 4.--Influence of intensive culture on basal area per acre in juvenile and mature wood of longleaf (LL), shortleaf (SL), and loblolly (LB) pine.

To evaluate the effects of cultural treatments on the amount of juvenile wood produced, we examined basal area. On the control plots, basal area per acre was highest for slash (fig. 4) because of better survival (300 trees/A) than tha of loblolly (230 trees/A) or longleaf (125 trees/A). Longleaf on the control plots produced only 19 percent of its basal area growth in juvenile wood compared to 33 percent for slash and 53 percent for loblolly (table 3) because radial growth of longleaf was slow during the first 8 years after planting. Cultivation with no fertilization did not increase basal area of loblolly or slash pine. However, cultivation for 3 years after planting significantly increased basal area per acre of longleaf juvenile wood because of increased radial growth the first few years after planting and improving survival from 125 trees pe acre on the control plots to 270 tree per acre on the cultivated plots. Use of new longleaf pine artificial regeneration techniques can reduce seedling mortality (Rounsaville 1985) and perhaps result in the establishment of fully stocked stands which contain a low proportion of juvenile wood, as occurred on the control plots.

At age 25, 24 years after fertilization, the basal area per acre on the cultivation plus fertilization plots was greater than that of the controls for all species (fig. 4). On the cultivation plus low level fertilization plots, longleaf and slash pine had about the same basal area per acre but the slash contained 10 percent less juvenile wood. Longleaf and loblolly produced more basal area per acre on the cultivated plus medium and high level fertilization plots than slash. However, the slash contained on the average 16 percent less juvenile wood.

Table 3--Average proportion of tree basal area in juvenile wood by species and levels of intensive culture for trees with average and high specific gravity parents

Species	Source[1]	Control	Treatment[2] Cultivation + No NPK	Cultivation + Low NPK	Cultivation + Med NPK	Cultivation + High NPK
			Percent			
LONGLEAF	AVG	19k[3]	52cdef	49defg	48defg	51bcdefg
	HIGH	19k	37hi	48defg	52bcdef	48defg
SLASH	AVG	36hi	44efgh	44efgh	50cdefg	44gh
	HIGH	27jk	30ij	42fgh	44efgh	41defg
LOBLOLLY	AVG	54abcde	57abcd	52bcdef	50cdefg	55abcd
	HIGH	51bcdefg	62a	60ab	64a	60ab

[1] ASG = Progeny of average specific gravity parents
HSG = Progeny of high specific gravity parents

[2] Low NPK = 1000 lbs 10-5-5 per acre
Med NPK = 2000 lbs 10-5-5 per acre
High NPK = 4000 lbs 10-5-5 per acre

[3] Values with the same letter do not differ at the 0.05 level according to Duncan's Multiple Range Test.

CONCLUSIONS

On a poor sandy-loam Coastal Plain site in southeastern Mississippi, cultivation plus fertilization at increasing levels 1 year after planting significantly increased diameter and height growth of longleaf, slash, and loblolly pine without reducing juvenile or mature wood weighted average SG. Cultivation without fertilization did not influence wood SG or increase growth of slash or loblolly pine. Cultivation alone significantly increased basal area per acre of longleaf pine by improving survival. Cultivation plus fertilization did not change the length of the juvenility period of loblolly or ASG slash progeny but did lengthen the juvenility period of HSG slash progeny by 2 years and longleaf ASG and HSG progeny by 4 years. The results regarding the effects of genetic selection for high SG on wood SG are inconclusive. The low selection differential in the parent population did not result in large enough differences in SG of the progeny to draw conclusion concerning these effects.

Average SG for juvenile wood of loblolly pine was significantly lower than that of longleaf and slash pine, but there was no significant difference in weighted mature wood SG between the three species.

Cultivation plus fertilization significantly increased basal area per acre in juvenile wood of all three species. Cultivation plus fertilization increased the proportion of juvenile wood in slash and longleaf but not in loblolly. At age 25, 24 years after fertilization, slash pine is outperforming longleaf and loblolly in basal area per acre on control plots and contains 33 percent of its basal area in juvenile wood compared to 53 percent for loblolly but only 19 percent for longleaf. On the cultivation plus low level fertilizer plots longleaf is doing as well as slash but contains 48 percent of its basal area in juvenile wood compared to 43 percent for slash. Loblolly and longleaf pines out-performed the slash on cultived and heavily fertilized plots but contained on the average 16 percent more basal area in juvenile wood.

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MICRO-COMPUTER MAP BASED DATA RETRIEVAL SYSTEM FOR FOREST MANAGERS[1]

Donald J. Lipscomb and Thomas M. Williams[2]

ABSTRACT[3].--Forest management decisions on the Hobcaw Experimental Forest are supported by a complete map based record system. Stand records were developed in Lotus spreadsheet files. Maps were created from USGS 1:100,000 Digital Line Graphs into ARC-INFO coverages with the Lotus spreadsheets merged to ARC-INFO tables by polygon numbers for each stand. Management decisions can be supported by this comercially available system with an investment of less than $10,000.

INTRODUCTION

Forest management is an unique activity in that it deals with a relatively low value product produced over long time periods. Even in the most productive areas investments made in forestry must be carried for more than twenty years. Foresters must be able to make management decisions without incurring large costs in information collection or management.

Foresters have traditionally made decisions based on management of basic units called stands. Maps are made of stand locations. Tabular data are collected on tree species, size, age, density, volume and growth rates; soil texture,drainage, and fertility; and other related measures such as stand area, understory vegetation and forest fire fuel loading. Management decisions on regeneration, intermediate treatments, and protection are based primarily on tabular data with maps used principally to locate stands, or areas of interest within stands.

Computers can enhance management of both tabular data and maps. Electronic spreadsheets and data base management systems (DBMS) greatly enhance the manipulation and reporting of tabular data. CAD (computer aided design) and map display programs produce maps in many useful forms. The combination of these two functions in a single computer software program, which can produce new maps from existing data, is called a geographic information system (GIS) (Devine 1987). GIS software is available for micro-computers in many forms with differing capabilities. However, full featured GIS systems are generally only available on mainframe or mini - computers. These programs contain many more algorithms and subroutines for map analysis than the micro-computer versions.

Recent literature contains examples of the usefulness of GIS for forest management decisions. Fujioka (1986) examined simulating fire weather danger in a spatial context. Berry (1986) produced detailed analysis of logging transportation costs in the forms of "timbershed maps". DeMars (1986) attempted to relate tree mortality to soil, elevation, slope, and aspect. Coulson et al. (1988) are developing an artificial intelligence - GIS interfaces to investigate ecological characteristics of Southern pine bark beetle infestations. Scott Paper Company maintains a GIS based file system on geographic data, tabular data, and forest inventory data for their approximately 500,000 acre forest holdings (Manogue 1987).

In most of the preceding examples a full featured GIS program is maintained on a mainframe computer. These GIS systems generally have multiple layers of map data and algorithms to manipulate data within or between layers. Such systems introduce high initial costs in two areas; acquisition of an accurate data base, and computer hardware and software. We propose a system which attacks both aspects of high cost, by combining purchased base digital data, micro-computer software, and existing forest tabular data. A low cost system of integrating map drawings into tabular data retrieval allows the forester to base decisions on both tabular information and spatial arrangements of the selected areas.

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[3] The authors would like to thank Mr. Steve Newman and Westvaco Corporation for assistance in transfer of digital data from mainframe to micro computer formats.

Decision making in forest management can be greatly enhanced by integration of stand maps with tabular data which is normally collected and stored for each management unit. Although a full featured geographic information system (GIS) may be desirable, most forest management decisions can be adequately served by a map based data retrieval system which adds the ability to display the tabular data in map graphics that represent real space.

SYSTEM DEVELOPMENT

Hardware

We used a Compaq Deskpro 386/16 with an 80287 based math coprocessor to build a stand alone system. This unit also has a hard disk capacity of 130 megabytes and two floppy disk drives, however, the system could function with less storage capacity. A high resolution color monitor and some type of graphic printing device are also basic to the system. We used the Compaq Enhanced Color Graphic Board with monitor and an Epson FX-286e dot matrix printer.

A minimum system consisting of an IBM PC-AT level micro- computer with math coprocessor and a standard forty megabyte hard disk plus one floppy disk device could also form the basis of a stand alone system on most medium size forests or blocks with fewer than 1000 polygons. A high resolution color monitor and some sort of graphic printing device would be necessary in such a minimum level system. Digitizing and plotting devices would add many capabilities, but are not absolutely necessary for a beginning integrated map data retrieval set up.

Software

The GIS software consisted of two packages, ESRI's PC ARC/INFO Starter Kit and PC ARCPLOT. These two software packages were used to integrate map polygons and tabular data. Again, there are many other software packages that would enhance the system and expand its capabilities, but these are enough for a beginning system. These two software packages allowed input of both map and tabular data directly. They allowed transfer of tabular data as properly formatted ASCII files from other sources. They also provided for integrated data/map query and output on the color monitor or as line plots via the printer.

Digital data for base maps are available from several federal agencies at low cost. The Geologic Survey has 1:100,000 scale data corresponding to their 30 x 30 minute quadrangle maps for the entire continental United States. The data is arranged by various themes (roads, hydrography, elevations, land use) for each quadrangle. Digital data is also available from the Geodetic Survey and the Census Bureau. The forester can greatly reduce the cost of his digital base map by making prudent use of these public data sources.

Creating the Database

The already existing stand record system contained information for two of the three components used to construct the new data base. Tabular data (age, species, volume, etc.) for each stand were maintained in a Lotus Symphony spreadsheet. Stand maps had been developed from aerial photographs with a scale of one inch to one thousand feet. The third component was digital data purchased from the USGS and down loaded from a mini-computer as ARC/INFO coverages of the specific areas of interest. This digital data came from 1:100,000-scale planimetric maps and contained two layers, hydrography and roads. This digital line graph data did not contain a lot of detail about the forest, but was needed because the existing stand maps did not contain controlled reference points. Since the property has water on three sides and many roads, these two layers were most helpful in completing a referenced base map.

The stand maps were digitized in a very crude and spatially inaccurate manner which purposefully ignored some of the usual procedure for producing quality GIS data sets. The objective of integrating map and tabular data for query and display was met. However, the map component can be updated with more spatially correct digital data at a later time as long as the polygon identifications, which are cross referenced to the tabular data for each stand, remain the same. The inch to one thousand foot stand maps on record were copied to clear overhead projection sheets and taped to the monitor screen using the hydrography and road features from the USGS digital line graph coverages as a base to orient and delineate boundary features. Overlays can be produced from any reasonably large scale map or photography since the base map can be displayed to any scale on the screen. Boundaries were traced on the screen with direct cursor controls using the ADS feature of PC ARC/INFO . Only polygons which described basic management units were identified and retained for connecting with the tabular data. Map of stand polygons were edited, cleaned, and topology built before entering or merging tabular data sets.

The tabular data for each stand contained many of the items typical of forest management records such as administrative identifiers, area, age, density, volume of various merchantable products, soil classes, overstory types, and so on. Our records were already in a Symphony data set which could easily be edited in the spreadsheet mode and saved as ASCII (print) files for transfer directly into the Tables component of PC ARC/INFO. A single column containing the unique identifier for each polygon representing an individual record was added to the front of the data set. Then another column (one character wide) containing commas was copied between each column (set of fields) before writing the ASCII file to the disk. If blank spaces in character (or label) fields are desired it is necessary to surround these with single or double quotes by copying the quotes to the appropriate positions. The data set was then saved (printed) to a disk in ASCII format.

Some preparation and manipulation was also necessary in the Tables module of PC ARC/INFO before transfer of the prepared files. The first step was to define a blank data base with a structure matching the ASCII file, by using the "define" command. Then the ASCII file was added to the defined database, using the "add" command, and checked for errors. The resulting "Tables" file had one column that corresponded to the polygon identification number in the polygon attribute table (PAT) of the map. The final step in merging the maps and tabular data was to join the created "Tables" file to the stand map polygon attribute table using the command "joinitem" in the PC ARC/INFO starter kit. The "joinitem" command allowed the use of subcommands to match polygon identification numbers from each file. The resulting file was given the appropriate coverage name followed by the ".PAT" suffix in order to be recognized by other PC ARC/INFO and ARCPLOT commands or modules. The resulting file was internal to the PC ARC/INFO system.

EXAMPLES OF IMPLEMENTATION

The result of this process was a database with integrated map and tabular data that had limited spatial analysis application, but could be used to duplicate many steps in the forest management and land use decision making process. The ability to query the data and report it in both tabular and map graphic forms adds a new insight and supports the traditional decision making process. Compare traditional graphics of stand age on Hobcaw Forest (fig. 1) with the same data displayed as a map (fig. 2). While the traditional bar graph shows relative acreages, the map adds information about position, distances and juxtaposition of the age classes. These additional elements are important to many forest management decisions. The ability to rapidly display these elements has not been available through traditional means or on micro-computers until now.

While traditional models assist forest management decision making by identifying and evaluating units with desirable, or undesirable, characteristics the display in map form, again, adds useful information. For example, stand susceptibility to attack by Southern Pine Beetles (Dendroctonus frontalis Zimm.) can be assessed by models such as CLEMBEETLE (Hedden 1985). Searching the data base for our research forest produces 17 loblolly or mixed pine stands with a basal area of greater than 90 square feet per acre and occupying poorly drained soils. (These search criteria correspond to the criteria which would produce a high hazard rating in an individual stand model).

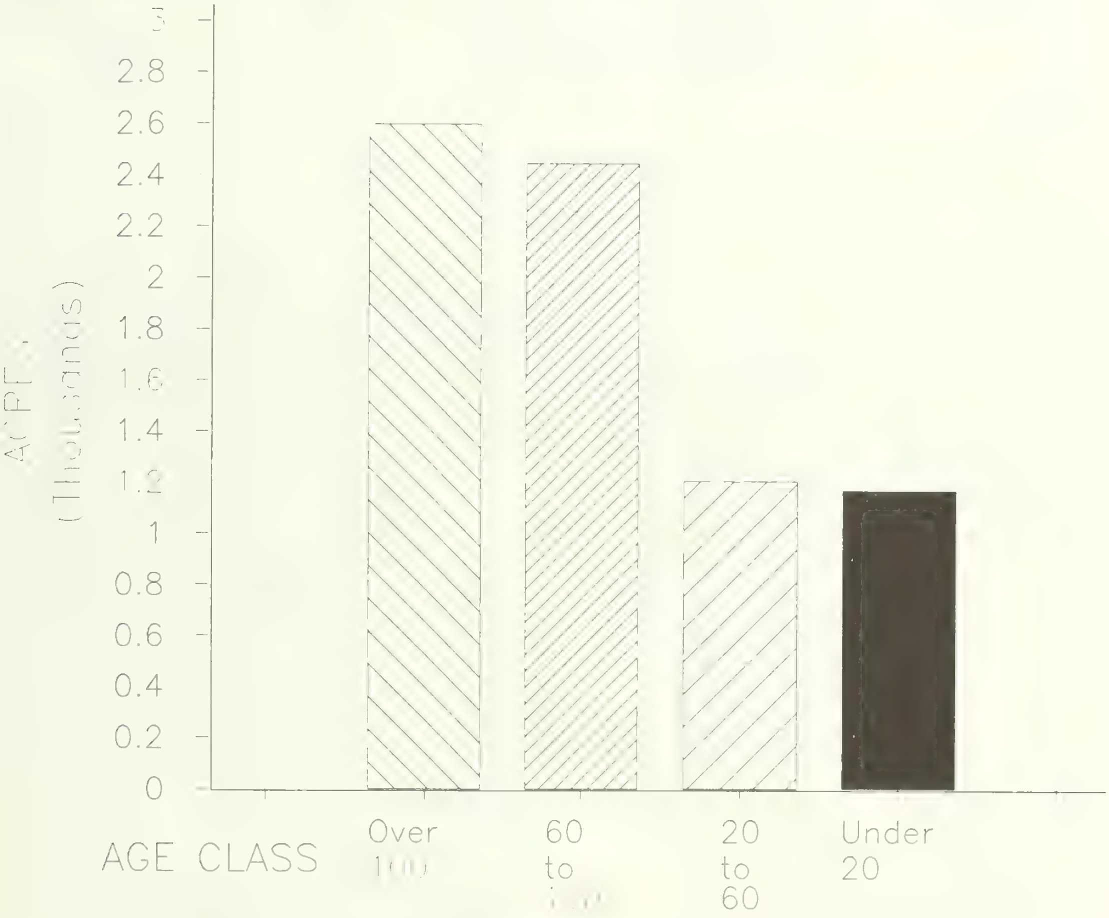

Figure 1.-- Age class distribution of Hobcaw Research Forest.

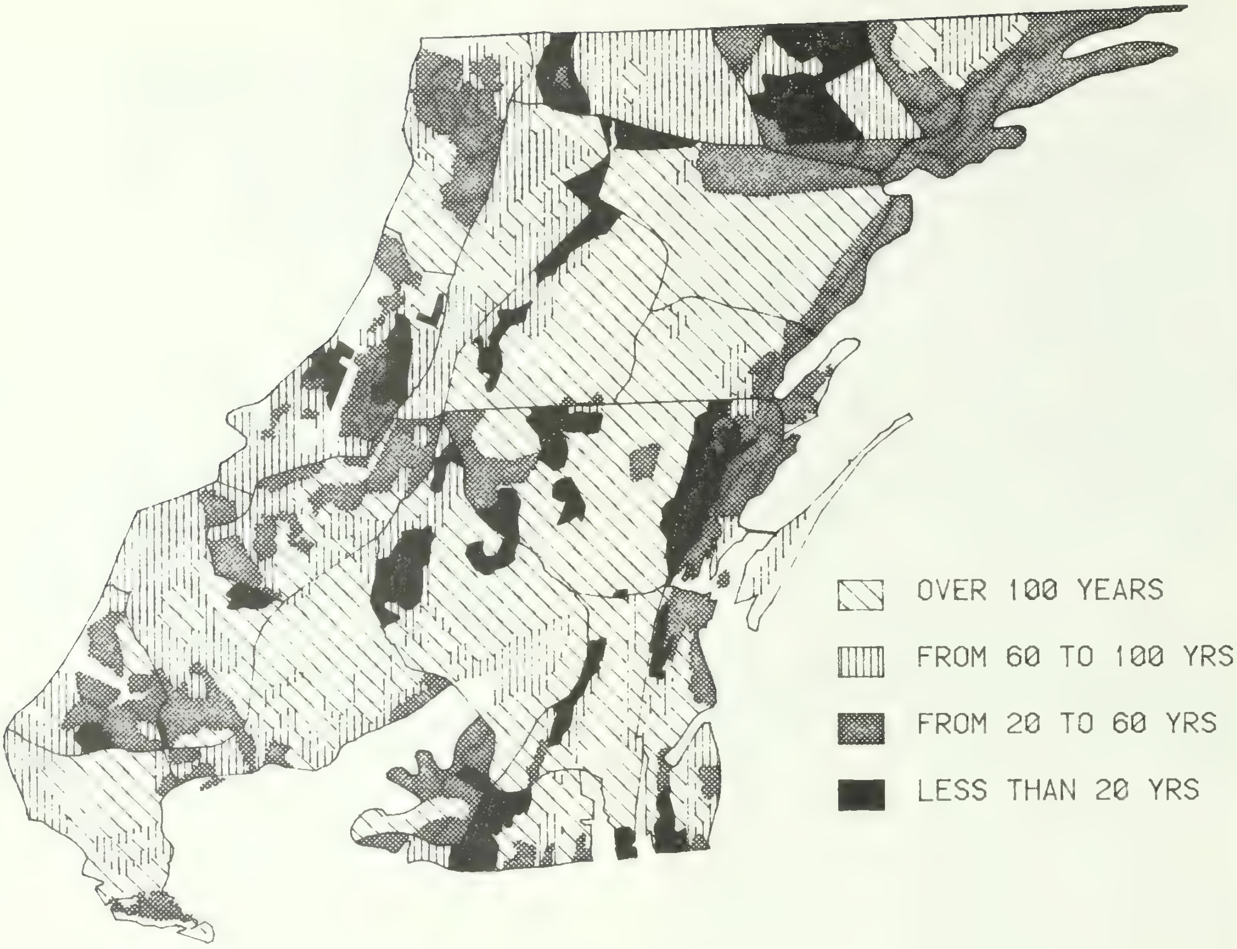

Figure 2.-- Map of age class distribution on Hobcaw Research Forest.

A map (fig. 3) of the high hazard stands shows their relation to hardwoods that are a barrier to beetle spread, low density longleaf stands that are less susceptible to beetle attack, and other loblolly and mixed pine stands that are susceptible to spot growth. The map shows that some of the high hazard stands are isolated and present little hazard to the surrounding forest, while others are adjacent or within an area of over a 1000 acres of susceptible forest. While many of the stands selected are too small to be economically thinned alone, a quick glance at the map shows that some stands are clustered along main roads and could be marketed as a unit. These important inputs to the decision making process could not be seen in the tabular data alone. This map integrated system allows the query to be done using PC ARCPLOT with maps displayed for visual inspection in a single step. Relative position of the sites can easily be seen and spatial and economic parameters which were a part of the tabular data set are still available.

Other examples might include selecting areas for thinning and grouping them for most efficient use of equipment based on predetermined factors of overstory type, age, and density. If horizontal diversity and juxtaposition of forest openings as they are cycled through time are important considerations such a system of integrated maps and tabular data is almost a necessity. However, none of these decision examples requires spatial correctness in the maps that cannot be replaced by information which is already a part of almost every forest manager's stand record system.

OBSERVATIONS AND LIMITATIONS

The map information generated by this system was not spatially accurate when compared with areas planimetered from photographs (fig. 4.). Errors, using the technique described, were on the same order as those found in Landsat digital data (Walsh et al. 1987). Most errors seem attributable to two causes. Single lines separating stands seem to have been misplaced resulting in over-estimated areas adjacent to under-estimated areas. Larger errors are clustered near marsh or bay boundaries while those boundaries defined by roads have smaller errors. One might suspect that roads could be more consistently defined between different map scales.

The maps produced by this technique have limited value for spatial analysis utilizing mathematical functions involving distance and could produce serious errors using overlay analysis.

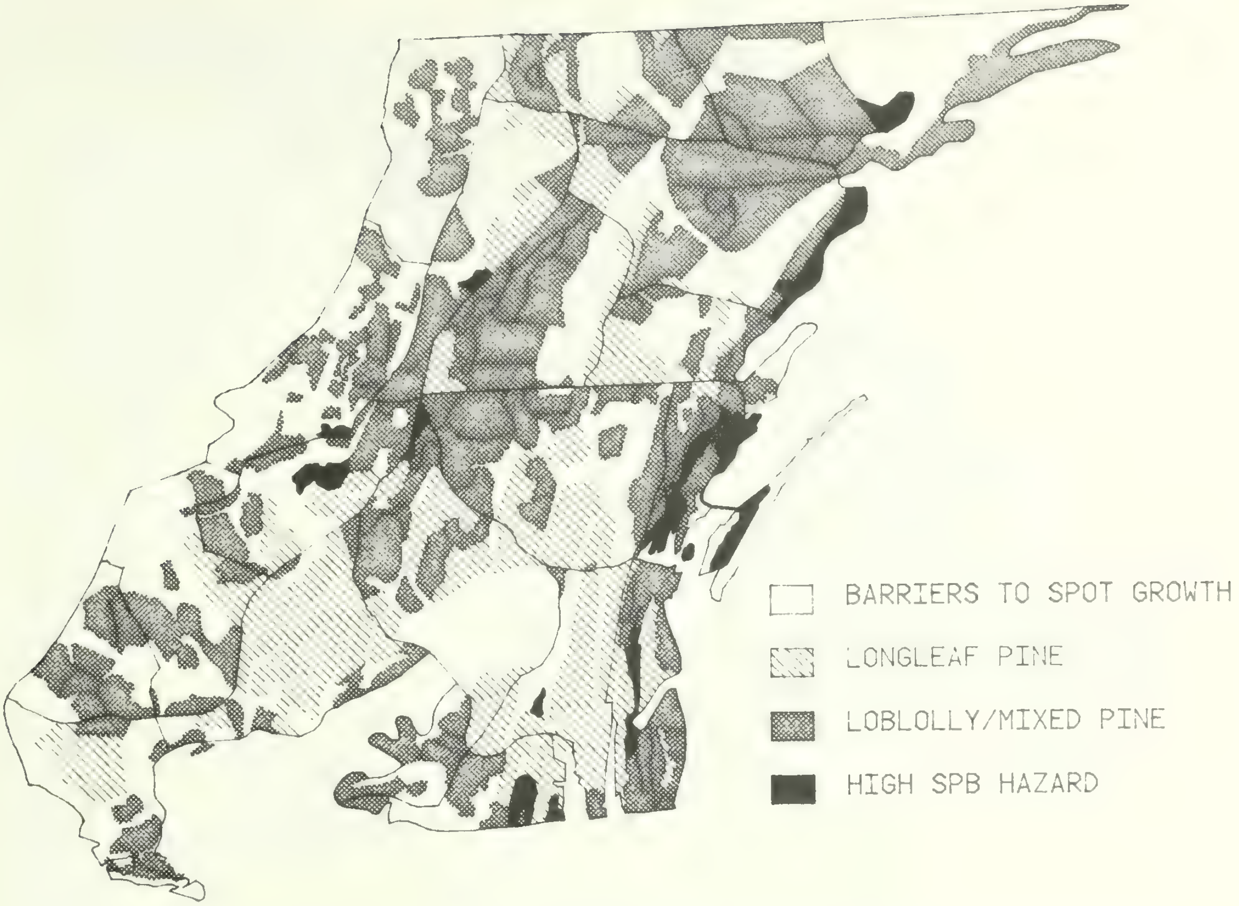

Figure 3-- Map of Hobcaw Research Forest showing stands selected as high southern pine beetle hazard based on species, density, and soil type.

The maps cannot be used for boundary definition in legal aspects of management, such as preparation of contracts for site preparation. Legal boundary descriptions and accurate areas contained in the tabular data could compensate for this limitation.

The base system described here will support forest management decisions as they are made today. The system will increase productivity (especially for foresters transferring into unfamiliar areas) by searching the tabular data for management criteria and simultaneously producing a map of the chosen stands.

The map will allow immediate qualitative judgements on spatial relations of the chosen stands. Rapid interactive display of results may also allow the manager to consider a larger number of options. The cost of such a basic map integrated data retrieval system may be much more attractive to the "grass roots" of the forest industry making land use and timber management decisions than the cost of purchasing and maintaining a full featured GIS.

The hardware used for this system limits the size of forest that it can be applied to. The base PC-AT system would support about a 1000 polygons and operate at an acceptable speed. If the average stand is 40 acres this would limit the working size to 40,000 acres. If the forest is larger than that some other option is needed. The simplest option is to add a tape drive to the computer. Tape drives costing about $500 can hold the entire contents of a 40 megabyte hard disk and can be loaded in less than 30 minutes. The management units can be treated as separate 40,000 acre areas with a tape for each area. At a higher cost very large disk drives (300+ megabytes) are available as are WORM (Write Once Read Many) optical disks. Either system will support many 40,000 acre blocks and the optical disks are ideal archival media.4

The PC ARC-INFO system can be included in a full blown GIS if the need arises or becomes desirable. Files made with the PC versions are compatible with mini and mainframe versions of ARC/INFO. Spatial analysis modules are also available for PC ARC/INFO. Large scale spatially correct data for such analysis will be very expensive. While it may not be practical to generate such digital data for forest management practices alone, many public service agencies are generating it for a broader spectrum of use. With the type of map integrated data retrieval system described here, forest managers can take advantage of the level of information they already have. They can update their maps with better data as it becomes available just as they now update their tabular data pertaining to stand records.

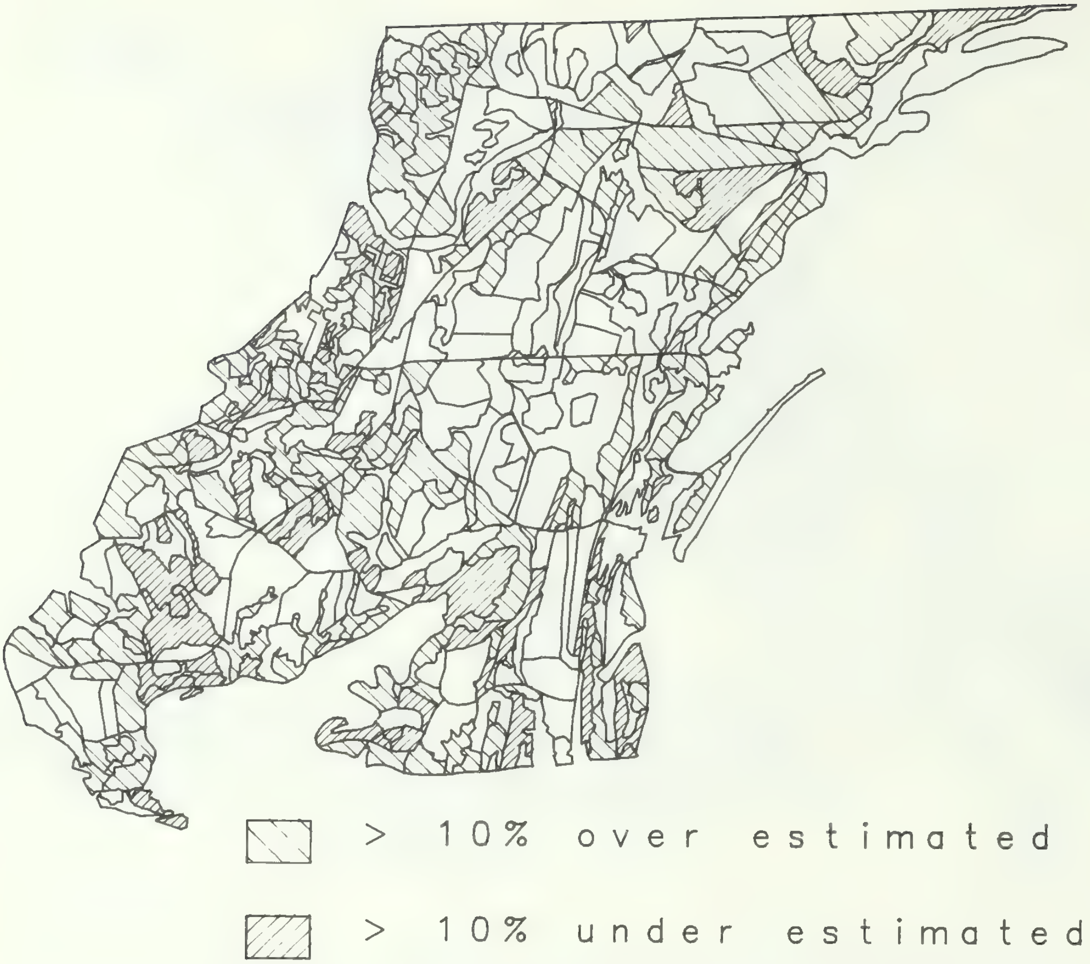

Figure 4-- Map of Hobcaw Research Forest showing errors in stand area. Error was computed as difference of GIS calculated area minus planimetered area expressed as a percentag of planimetered data.

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LONG-TERM EFFECTS OF SOIL DRAINAGE, SPACING, AND SITE PREPARATION ON HEIGHT AND STAND VOLUME GROWTH OF SLASH PINE[1]

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Abstract.--Soil drainage, spacing, and site preparation effects on height and stand volume growth in slash pine (Pinus elliottii Englm.) plantations in the Southeastern Coastal Plain of Georgia were analyzed. The moderately well-drained Orsino soil produced the best early height growth, but by age 25 ranked third and produced significantly shorter trees than those on Leon and Mascotte soils. Spacing had little effect on tree heights until late in the study when the 6 x 6-foot spacing resulted in reduced codominant and dominant tree heights. By age 25, the control, i.e., broadcast burn only, produced stand volumes and codominant and dominant tree heights similar to that on the more intensely prepared bed and harrow treatments on two of the four soil series. Culmination of mean annual increment occurred earlier on the better drained soils and on the more intensively prepared sites. Scalping proved detrimental to growth, producing inferior mean height and volume.

INTRODUCTION

Most site preparation methods produce significantly better growth, survival, and yield responses than no site preparation (Mann and Derr 1970, May and others 1973). Large growth gains demonstrated in early research findings, along with easier planting conditions, encouraged site preparation technology to develop toward a "bare-the-site" ideal (Haines and others 1974). Some studies, however, questioned the need, desirability, and economic feasibility of intensive site preparation to achieve regeneration goals on many Southern forest sites (Cain 1978; Outcalt 1982, 1984).

There are relatively few long-term studies regarding effects of site preparation on growth of Southern pines. Do early growth benefits from intensive site preparation techniques carry through to the end of the rotation? Some studies indicate that growth gains from intensive site preparation treatments, such as bedding, may lessen with time (Cain 1978, Mann and McGilvray 1974, McKee and Wilhite 1986).

Information is needed regarding long-term responses to site preparation treatments, as well as how these responses vary with differences in tree spacing and soil drainage. This paper reports on the effects of these variables on the growth of slash pine.

METHODS

Brunswick Pulp and Paper Company, with the aid and cooperation of T. S. Coile and F. X. Schumacher, designed an experiment in 1956 to test different spacing levels and site preparation intensities on the survival, growth, and yield of slash pine on different soils in the Atlantic Coastal Plain (fig. 1). The study area was located in Camden, Clinch, and Wayne counties of southeast Georgia. The experimental design was a split-plot randomized complete block design with two replications or blocks for each of four drainage classes, i.e., soil series. Blocks were divided into four 1-ac plots, each of which was assigned a spacing, which ranged from 6 x 6 to 12 x 12 ft. Spacing plots were further divided into four subplots and randomly assigned a site preparation treatment.

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SPACING

10 x 10	6 x 12	12 x 12	6 x 6
SITE PREPARATION			
C	H	B	S
H	S	S	C
B	C	H	B
S	B	C	H

Figure 1.--A schematic representation of the experimental design: Split-plot randomized complete block design. 1 of 2 replications at one location. C=control, S=scalp, B=bed, H=harrow.

Site preparation treatments included: (1) Control-plots were broadcast burned in May 1957 and received no mechanical site preparation treatment. (2) Scalp-plots were burned immediately prior to planting in December 1957 and a Mathis fire line construction plow set very shallow (1-2 inches) was used to scalp the soil surface. This treatment simulated conditions existing when the plow is placed in front of the planting machine to form a shallow trench. (3) Bed-plots were burned in May 1957 and plowed strips prepared immediately following burning. Furrowed strips were made with a Caterpiller D-4 tractor and a Mathis fire-line construction plow first throwing out the sod and soil on row centers. These furrowed strips were then pulled in twice with an Athens fire-line maintenance harrow, once in June and again in August 1957. (4) Harrow-plots were burned in May 1957 and immediately harrowed completely with a Caterpiller D-4 tractor and a 7-foot Rome offset harrow, then reharrowed in August 1957. Dibble planting, using company-grown 1-0 slash pine stock on all plots, started December 30, 1957 and continued through February 1958 (Worst 1964).

Each block was installed on one of the following four soil series (table 1): (1) Orsino: sandy siliceous, uncoated family of Spodic Quartzipsamments. Moderately well drained. (2) Leon: sandy, siliceous family of Aeric Haplaquods. Somewhat poorly drained. (3) Mascotte: sandy over loamy, siliceous family of Ultic Haplaquods. Somewhat poorly to poorly drained. (4) Pelham: loamy, siliceous family of Arenic Paleaquults. Poorly Drained.

Previous reports and articles have documented results of this study at various developmental stages (May and others 1973, Sarigumba 1984, Sarigumba and Anderson 1979, Smith and Anderson 1977, Worst 1964). Survival, diameter, height, fusiform rust incidence, and volume differences have been discussed previously. In this study, heights of codominant and dominant trees, merchantable volume at age 25, and mean annual increment (MAI) are discussed.

Table 1.--Some characteristics of soils in a spacing and site preparation study in the Coastal Plain of southeastern Georgia (Sarigumba 1984).

Soil Series	Depth (inches)		Drainage Class
	Bh*	Bt**	
Orsino	16-21	-----	moderately well
Leon	16-30	-----	somewhat poorly
Mascotte	16-28	36-60	somewhat poorly to poorly
Pelham	-----	26-39	poorly

* Bh = organic pan or spodic horizon
** Bt = clayey accumulation or argillic horizon

The 20 tallest trees for each location, treatment, and spacing combination were analyzed to determine if codominant and dominant height were affected by soil series/drainage, spacing, or site preparation treatment. For age 10 and continuing periodically through age 25, an analysis of variance was performed to determine if treatment means differed significantly. Duncan's New Multiple Range Procedure was the testing criteria used to separate treatment means (alpha=5%). Before main effects of these treatments could be determined, the interactions Location x Spacing x Treatment, Location x Spacing, Location x Treatment, and Spacing x Treatment were analyzed to discern if any "masking" were present in each measurement year.

Age of maximum mean annual increment was determined for each site preparation treatment. Spacings were pooled for each location. Measured heights and diameters were used in a stem volume equation developed by Brister and others (1980) for site-prepared slash pine plantations in the Lower Coastal Plain of Georgia and Florida to generate merchantable volumes from age 10 to 25.

The equation used as a model to characterize the merchantable volume-age relationship was the Chapman-Richards generalization of Von-Bertalanffy' growth model (Pienaar and Turnbull 1973). The equation is the integral form of the differential equation:

$$\frac{dv}{dt} = a \times V^{b} - m \times V$$

where V = Merchantable volume in cubic feet at age
t = Plantation age in years
a,b,m = Coefficients to be estimated.

The integral form of this differential equation is

$$V = A[1-B \exp(-kt)]^{(1/1-m)} + e$$

where V = Merchantable volume in cubic feet at age
t = Plantation age in years
A,B,k,m = Coefficients to be estimated
e = Random error term.

This non-linear growth model is an increasing ogive (i.e., with an inflection point at some age $t>0$) if $k>0$ and $0<m<1$.

$$y(0) = 0$$

$$y(\infty) = A$$

Inflection occurs at $y(t) = A[m^{(1/1-m)}]$ and at age $t = -1/k \log (1-m)$.

Note that $y(t)< 1/2A$ always, so age t always is less than age to half growth.

Reparameterized: $y(t) = A(1-e^{kt})^{1/1-m}$
$= A(1-U^{-t/T})^{U}$

where $T>0$, $U>1$

$$\frac{dy}{dA} = (1-U^{-t/T})^{U} = p^{U}$$

where $p = (1-U^{-t/T})$

$$\frac{dy}{dT} = -At/t^{2}(U\log U \text{ x } (1-p)p^{U-1})$$

$$\frac{dy}{dU} = A(p^{U}\log p + t/T(1-p)p^{U-1})$$

** $y(T)<e^{-1}(\cong 0.3679)$
A,U,T = parameters to be estimated

where A = upper asymptotic growth value
U = age at which maximum instantaneous growth rate occurs
T = shape parameter.

Once the three parameters were defined for each location/site preparation treatment combination, merchantable volume from age 10 through age 50 was generated using a BASIC computer program. To obtain mean annual increment (MAI), the volume generated at each age was divided by the age. Culmination of MAI occurred in the year of the largest MAI value.

RESULTS AND DISCUSSION

Height of Codominant and Dominant Trees

When parameters not in question were pooled, average height of codominant and dominant trees at age 10 ranged from 22 to 29 feet across the four soil series (table 2). Trees on the moderately well-drained Orsino soil were significantly taller than those on the other soils. Codominant and dominant heights at age 17 ranged from 41 to 47 feet. The moderately well-drained Orsino soil no longer ranked first as the somewhat poorly-drained Leon soil produced slightly taller site index trees (0.5 feet taller) by age 17. Average heights of codominant and dominant trees ranged from 58 to 63 feet at age 25. Trees on the poorer drained Mascotte and Pelham soils were catching up with those on the better drained Leon and Orsino soils. The poorly drained Pelham soil produced site index trees of the same height as those produced on the moderately well-drained Orsino soil.

Table 2.--The effect of soil drainage on codominant/dominant height from age 10 to age 25.

Soil Series	Age (years) 10	17	25
	---------Height (feet)---------		
Orsino	29a[1]	47a	58c
Leon	24b	47a	63a
Mascotte	22c	45b	60b
Pelham	23bc	41c	58c

[1] Means with same letter within each age are not significantly different (alpha = .05).

Height growth patterns changed with time among drainage classes as depicted by a change in ranking between age 10 and 17 (occurring at age 14). On the better drained sites (i.e., the moderately well-drained Orsino soil), establishment and early growth is rapid because seedlings have adequate rooting volume where excessive soil moisture is not limiting. On poorer drained soils, early growth is slower due to higher water tables (McKee and Wilhite 1986). However, once canopy closure occurs and the water table is lowered by evapotranspiration, trees on these poorly drained soils are able to take advantage of high moisture levels and begin to out-perform those on better drained sites where moisture has become limiting.

The bed and harrow treatments produced significantly taller trees than the scalp and control treatments throughout the measurement period (table 3). Sarigumba (1984) noted that calculated height and volume F-values generally declined as a function of soil series and site preparation treatment but were still significant at age 25. Through age 20, growth from scalping was inferior to that of all other site preparation treatments. Heights of codominant and dominant trees were not significantly different between the control and scalp treatment by age 25, probably because soil displacement was not great with the scalping method used in this study. Windrowing practices which move soil over much larger distances would probably be even more detrimental to growth (Glass 1976).

Spacing had no significant effect on codominant and dominant tree heights from age 10 through age 20 (table 4). However, by age 25, the 6 x 6-foot spacing produced shorter trees than the 6 x 12, 10 x 10, and 12 x 12-foot spacings. Borders and Bailey (1985) also found that, by age 20, stands planted with 1200 stems/ac showed a 3 to 5-foot reduction in dominant tree height compared to stands planted with a lower initial stocking density.

Table 3.--The effect of site preparation on codominant/dominant height from age 10 to age 25.

Treatment	Age (years) 10	17	25
	---------Height (feet)---------		
Harrow	27a[1]	47a	62a
Bed	26a	47a	61a
Control	23b	44b	59b
Scalp	21c	42c	58b

[1] Means with same letter within each age are not significantly different (alpha = .05).

Table 4.--The effect of spacing on codominant/ dominant height from age 10 to age 25.

Spacing	Age (years) 10	17	25
	---------Height (feet)---------		
6 x 6	25a[1]	44a	57b
6 x 12	24a	45a	61a
10 x 10	24a	45a	60a
12 x 12	24a	45a	61a

[1] Means with same letter within each age are not significantly different (alpha = .05).

Culmination of Mean Annual Increment - Age 25 Volume

Various non-linear growth models were employed to determine age of maximum mean annual increment for each site preparation treatment. A Chapman-Richards generalization of von-Bertalanffy's growth model best characterized growth over time. Age of maximum mean annual increment on the Orsino soil was as follows: Harrow--age 22 with a MAI of 130.3 merchantable (3-inch outside bark) ft^3/ac/yr; Bed--age 21 with a MAI of 109.8 ft^3/ac/yr; Control--age 33 with a MAI of 101.4 ft^3/ac/yr; and Scalp--age 33 with a MAI of 89.2 ft^3/ac/yr (fig. 2). By age 31, the control treatment had a greater projected MAI than the bed treatment. Using growth parameters particular to each treatment-soil series combination, projected MAI of the harrow treatment approached that of the control near age 50.

On the Leon soil, the harrow treatment performed best until age 27, producing a maximum MAI of 122.3 ft^3/ac/yr by age 23. Bedding produced a maximum MAI of 120.6 ft^3/ac/yr at age 24 and surpassed harrowing at age 27. The control treatment ranked third producing 110.3 ft^3/ac/yr at age 29, while scalping was last producing 100.6 ft^3/ac/yr at age 26. Maximum MAI of the control treatment was projected to surpass that of the bedding and harrowing treatments at age 32 (fig. 3).

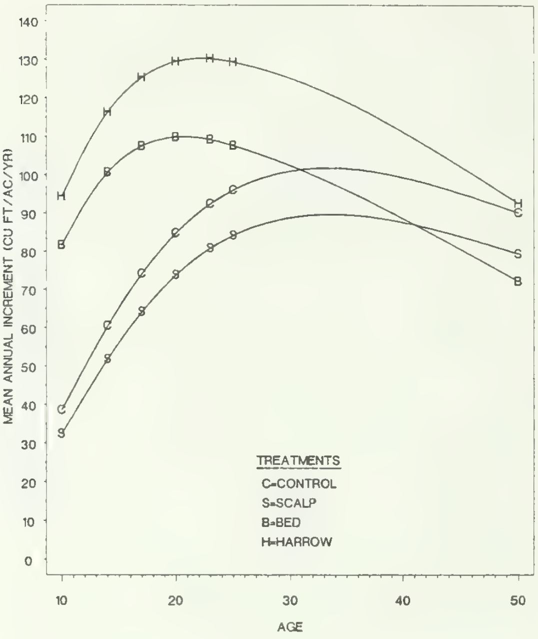

Figure 2.--Mean annual increment curves on a moderately well-drained Orsino soil.

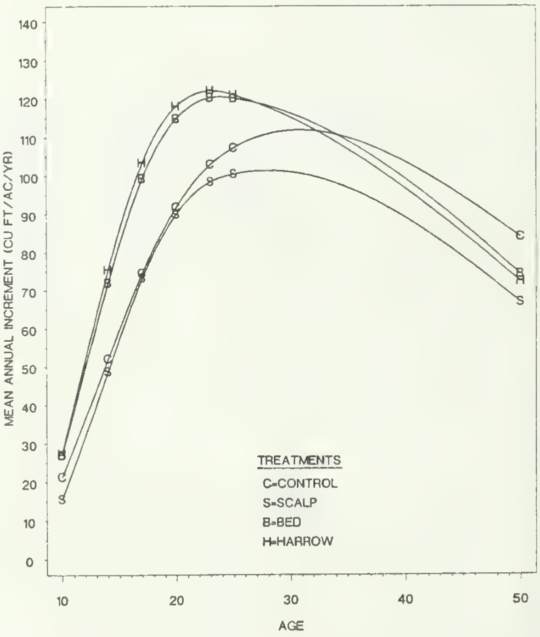

Figure 3.--Mean annual increment curves on a somewhat poorly-drained Leon soil.

On the somewhat poorly to poorly-drained Mascotte soil, harrowing ranked first with a maximum MAI of 122.8 ft^3/ac/yr at age 28 (fig. 4). Bedding was second with a maximum MAI of 115.7 ft^3/ac/yr at age 28, while the control ranked third with a maximum MAI of 95.1 ft^3/ac/yr at age 30. Scalping was last with a maximum MAI of 81.7 ft^3/ac/yr at age 33. The control treatment did not have any predicted values for MAI that surpass that for bedding or harrowing through age 50. However, the difference between the control and the more intensive treatments was projected to progressively decrease after age 30.

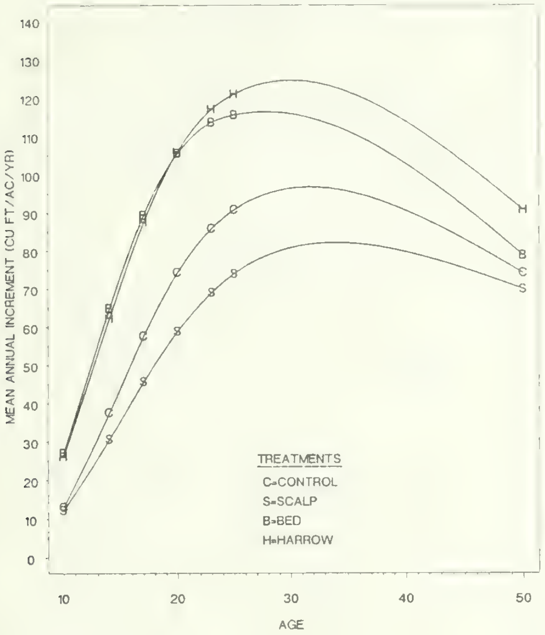

Figure 4.--Mean annual increment curves on a somewhat poorly drained Mascotte soil.

On the poorly drained Pelham soil, the control had the highest predicted value for maximum MAI, which occurred at a predicted age of 42 and produced 126.6 ft^3/ac/yr (fig. 5). Bedding was second with a predicted maximum MAI of 111.5 ft^3/ac/yr occurring at age 29, while harrowing ranked third with a predicted value of 110.0 ft^3/ac/yr at age 32. Scalping was last with 102.4 ft^3/ac/yr at age 33. Maximum MAI of the control surpassed that of the bedding treatment at age 30 and the harrow treatment at age 29.

Merchantable volume at age 25 ranged from a low of 1745 ft^3/ac for scalping on the Mascotte soil to a high of 3420 ft^3/ac for harrowing on the Orsino soil (table 5). There was no significant effect of site preparation on volume at age 25 on the Leon soil. Across all four soil series, the harrowing and bedding ranked first and second with harrowing ranking first except on the poorly-drained Pelham soil. The control treatment through age 25 produced volumes not significantly different than that of the bed and harrow treatment on two of the four soil series. Scalping always ranked last because of soil and forest floor displacement.

SUMMARY AND CONCLUSIONS

This study illustrates the value of long-term studies. Forest stands are dynamic and early- to mid-rotation findings can be misleading. Although the Orsino soil produced the tallest codominant/dominant trees at age 10, its ranking dropped to third by age 25. By age 25, stand volume on the control plots, which were only broadcast burned, was not significantly different than that produced on the intensively prepared bed and harrow plots on two of the four soil series.

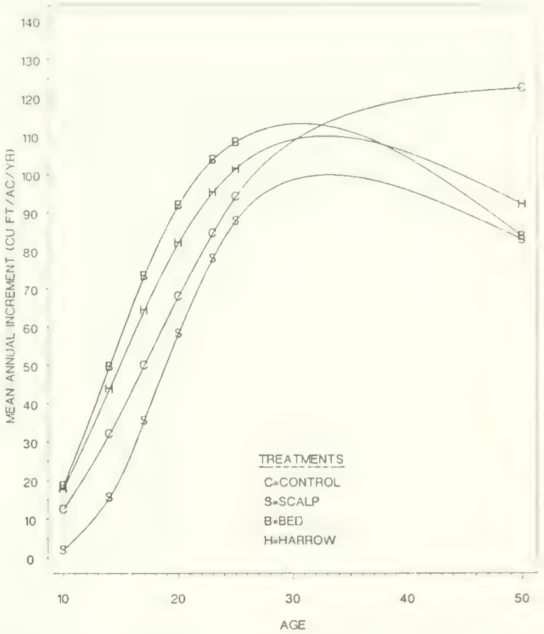

Figure 5.--Mean annual increment curves on a somewhat poorly drained Pelham soil.

Table 5.--The effect of site preparation and soil series on merchantable volume of slash pine through age 25.

Location	Treatment	Mean[1] (ft^3/ac)
Orsino	Harrow	3420a
	Bed	2700b
	Control	2395c
	Scalp	2110d
Leon	Harrow	3080a
	Bed	3025a
	Control	2720a
	Scalp	2530a
Mascotte	Harrow	3060a
	Bed	2910a
	Control	2300b
	Scalp	1745c
Pelham	Harrow	2545ab
	Bed	2735a
	Control	2365ab
	Scalp	2160b

[1] Means within each location with same letter are not significantly different (alpha = .05).

Age of maximum mean annual increment (MAI) occurred earlier for the bed and harrow treatments than for the control and scalp treatments across the four soil series. These intensive site preparation treatments help private industries achieve their goal of maximizing fiber production in the shortest period of time. Conversely, a broadcast burn is a viable alternative for the private landowner because yields are often satisfactory, yet establishment costs are much reduced. An economic comparison of various treatments will be presented in another paper.

Scalping displaced much of the forest floor and topsoil. This treatment adversely affected growth, producing lower mean volumes and heights across all four soil series. Scalping simulates windrowing, a site preparation practice widely used across the South. If scalping, which moves topsoil only a small distance, significantly reduced productivity, then large-scale displacement of topsoil by windrowing raises serious questions concerning the use of this method as a site preparation treatment.

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OBJECTIVE REGULATION OF SELECTION-MANAGED STANDS [1] OF SOUTHERN PINE - A PROGRESS REPORT

Robert M. Farrar, Jr. and Paul A. Murphy [2]

Abstract. -- Results are presented from the initial nominal 5-year cutting cycle in the first known attempt to objectively regulate uneven-aged stands of southern pine. The method of regulation employed, known as "Basal Area - Dmax - q" (B-D-q), objectively specifies a target residual stand table at the start of the cutting cycle. Various B-D-q structures were applied to 16 stands of mixed loblolly/shortleaf pine, varying from about 4 to 10 acres in size, which were inventoried and cut to leave such specified structures. The stands had competing hardwoods controlled, and were re-inventoried after a nominal growth period of 5 years. Cubic-foot and board-foot volume production was generally good, and development of reproduction is apparently adequate in most cases. Observations on stand development and necessary modifications in practices are also presented. The results should particularly interest those foresters involved in the management of naturally regenerated timber stands.[3]

INTRODUCTION

Much useful information has been developed on gulation of uneven-aged loblolly-shortleaf pine *inus taeda* L. and *P. echinata* Mill.) stands in uth Arkansas and north Louisiana (Reynolds 1959, 969; Reynolds and others 1984; Farrar 1984; Farrar nd others 1984). The method employed was ssentially volume control in the sawtimber omponent using a guiding d.b.h. limit with no ormal regulation of the sub-sawtimber component. he merchantable sub-sawtimber was marked for arvesting according to a subjective evaluation of he silvicultural needs of the stand. That stand productivity could be improved, good periodic harvests sustained, and a tentative optimum stand structure identified for site-index class 90 (loblolly) land attest to its effectiveness.

However, the method does have drawbacks:

(1) It is rather subjective and requires considerable skill in deciding which trees to cut, particularly in the unregulated sub-sawtimber component.

(2) No formal attention is paid to the sub-merchantable stand to ensure reproduction and recruitment into the merchantable stand.

(3) Because of (1) and (2), the method may be difficult to understand or to apply with confidence by those unfamiliar with the selection system.

A more objective way of regulating is to strictly specify the residual total stand structure to be left after cutting. But there are no known results of such work in southern pine stands. The most promising method of prescribing such structure is the "basal area - maximum d.b.h. - q" (or B-D-q) method used most notably in the northeastern United States (Marquis 1978). Basal area (BA or B) is the total square feet of basal area per acre (d.b.h. > 0.5 inch) to be left in the residual stand after a cut. Maximum d.b.h. (Dmax or D) is the largest d.b.h. class to be left on the area. In a balanced uneven-aged stand, the constant q is the ratio of the number of trees in a given d.b.h. class to the number in the adjacent larger d.b.h. class. In this method, q is used to distribute the BA over all the d.b.h. classes between a minimum d.b.h. and Dmax.

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[3] The authors are indebted to Poison Springs tate Forest, Arkansas Forestry Commission, Camden, R; the Department of Forest Resources, University Arkansas at Monticello; the Georgia-Pacific rporation, Crossett, AR; and the International aper Company, Sheridan, AR, for study areas, ssistance in data collection, performing the quired treatments, and providing the required otection of their study locations.

Unless otherwise noted, the q is for 1-inch d.b.h. classes.

If q is stable or changes predictably with time, then this regulation system has considerable predictive potential, providing the future BA and Dmax are also predictable. We already have evidence that BA growth in uneven-aged loblolly-shortleaf is predictable (Murphy and Farrar 1982, 1983). The future Dmax is at least predictable from increment cores and is probably predictable from stand variables such as initial BA, mean d.b.h. and/or Dmax, and elapsed time. However, it is very difficult to leave stands with balanced uneven-aged structures because of the inherent variability of d.b.h. distributions, vagaries of cutting, and subsequent periodic mortality. But, even if the B-D-q technique proves to have limited predictive ability, it still forms a useful basis for objective regulation (Farrar 1984) much as basal area is a good basis for specifying residual even-aged stand density. In addition, this method of regulation is usually more easily applied by those unfamiliar with uneven-aged systems because of its objectivity.

We started investigating use of the B-D-q method in 1980 (Farrar 1981) by installing several studies and demonstrations in southern pine stands. The purposes of the study reported on here are to obtain experience in application of the B-D-q method to southern pine, to determine the stability of established B-D-q structures over time, to provide objective regulation of selection stands included the watershed studies of a cooperator, and to furnish demonstration areas for technology transfe activities. This is a report on our results to date.

METHODS

Study Areas

Sixteen objectively regulated stands, varying from about 4 to 10 acres in size, are included in the study. All stands are loblolly-shortleaf pine mixtures, with loblolly predominating. The site index (base age 50 years, U. S. Forest Service 197 varies from 68 to 97 feet for loblolly pine (table 1).

The stands are listed in table 1, and subsequent tables, in general order of installation and groupe by similar treatment. Seven stands are located on the rolling loamy Coastal Plain in Drew County near Monticello, Arkansas -- four on the University of Arkansas at Monticello (UAM) School Forest and thre on experimental watersheds (AR907). Six stands are located in the Coastal Plain on the flat, loess-capped soils of the Crossett Experimental Forest (CEF) in Ashley County, Arkansas. Three stands are located in the rolling sandy Coastal Plain on Po

Table 1. -- Before-cut and initial removal values at start of first cutting cycle, merchantable stand [1/]

Stand & location	Acres	SI	Date	Before-cut stand values TPA	BA	MCF	SCF	Doyle	Initial marked removals TPA	BA	MCF	SCF	Doyle
12 UAM	10.12	79	9/80	99	80	2,555	2,206	9,062	28	31	1,057	969	4,186
13 UAM	9.75	77	10/80	75	63	2,074	1,816	7,701	8	15	557	530	2,555
11 UAM	9.77	74	9/80	127	75	2,213	1,760	6,522	33	35	1,140	1,025	3,845
14 UAM	7.92	78	10/80	115	85	2,704	2,261	9,693	28	45	1,619	1,524	7,018
2 AR907	8.21	88	2/81	72	48	1,556	1,252	4,823	3	6	207	198	915
4 AR907	7.12	89	2/81	95	86	2,907	2,482	9,732	28	38	1,354	1,264	5,207
8 AR907	7.42	81	2/81	217	110	3,186	2,093	6,658	86	46	1,324	805	2,330
3 CEF54	9.95	95	8/80	149	108	3,773	3,126	13,664	43	55	2,110	1,919	8,927
3 PSSF	10.00	68	8/81	151	69	1,732	1,336	4,622	7	8	249	225	790
5 CEF61	4.59	93	8/81	180	115	3,919	3,202	14,707	47	51	1,925	1,741	8,928
1 CEF54	10.11	93	8/80	103	99	3,634	3,206	15,196	35	69	2,771	2,656	13,363
1 PSSF	10.00	70	8/81	173	68	1,627	1,199	4,166	24	18	539	492	1,947
8 CEF61	4.41	97	8/81	155	100	3,334	2,620	9,139	50	48	1,714	1,495	5,313
2 CEF54	10.10	92	8/80	134	94	3,290	2,740	12,881	46	73	2,830	2,670	12,773
2 PSSF	10.08	77	9/81	181	73	1,724	1,239	4,294	27	32	1,020	935	3,529
4 CEF61	4.32	96	8/81	184	101	3,257	2,460	9,107	50	59	2,201	2,025	7,987

[1/]

Merchantable Stand = trees > 3.5 in d.b.h.
SI = site index, index age 50 years, loblolly pine.
TPA = trees per acre.
BA = basal area per acre, ft^2
MCF = merch. ft^3, inside bark (i.b.), per acre; d.b.h. > 3.5 in; 3 in, i.b., top.
SCF = sawtimber ft^3, i.b., per acre; d.b.h. > 9.5 in; 7 in, i.b., top.
Doyle = sawtimber board feet per acre, Doyle log rule.

Springs State Forest (PSSF) near Camden in Ouachita County, Arkansas.

The stands were surveyed to obtain accurate acreage values, and all boundaries were identified such that there were no ambiguous "line" trees. All stands were then inventoried 100 percent by 1-inch d.b.h. classes for live pines with d.b.h. > 3.5 inches, both before-cut and after-cut. The marking tallies were also 100 percent by 1-inch d.b.h. classes. Diameter tapes were used throughout to measure d.b.h. and classify trees into 1-inch d.b.h. classes. All stands were initially inventoried (before-cut) and marked for cut during the same dormant season. Because of scheduling difficulties, some stands were not cut until a growing season had occurred. This caused some stands to have 6 years in the growth period rather than 5. However, in the future, both inventories, the marking, and the cutting will all occur in the same dormant season. Local cubic-foot and board-foot volume functions were developed for each location (UAM, AR907, CEF, and PSSF) using sample tree data and tree stem-profile functions (Farrar and Murphy 1987, 1988). These local functions were used to estimate all stand volumes. Unless stated otherwise, all values are per acre.

Initial Inventories

The initial before-cut stand data are given in table 1. Stand volumes varied from about 1,600 to 3,000 cubic feet and from about 4,200 to 15,000 [illegible] feet Doyle. All stands, except one (AR907 stand 2), had sufficient basal area to enable leaving the prescribed densities after cutting.

Table 2 presents the target residual and actual initial residual stand structures. The after-cut q for the stand 1-inch d.b.h. and larger is obtained from inventory data via linear regression:

$$\ln(N_i) = a + b(D_i),\ \text{where}$$

N_i = number of trees per acre in the ith d.b.h. class and

D_i = midpoint of the ith d.b.h. class.

From this equation, $q = e^{|b|}$.

Most stands had a past history of selection management but none had been cut for 5 to 15 years or longer. Consequently, very few stands had structures that allowed leaving the B-D-q structures as specified in table 2, but at least the required residual basal area could have been left in all but one (AR907 stand 2). The UAM and CEF54 stands were installed and treated during 1980-81. The AR907, PSSF, and CEF61 stands were installed during 1981-82. The PSSF stands were an exception in that they did have good reverse-J d.b.h. distributions characteristic of selection stands. The CEF61 stands were added because CEF54 stands 1 and 2 were severely reduced in density by a combination of overcutting, logging damage, and wind damage from two storms.

Table 2. -- Before-cut, target, and actual after-cut structures at start of first cutting cycle, total stand [1]

Stand & location	Before-cut structure				Target after-cut atructure			Actual after-cut structure			
	Date	BA	Dmax	q	BA	Dmax	q	Date	BA	Dmax	q
12 UAM	9/80	80	30	1.2	50	22	1.1	2/81	49	22	1.1
13 UAM	10/80	64	27	1.1	50	22	1.1	2/81	50	23	1.1
11 UAM	9/80	77	28	1.2	50	22	1.3	2/81	40	22	1.2
14 UAM	10/80	86	30	1.2	50	22	1.3	4/81	41	22	1.2
2 AR907	2/81	48	25	1.2	60	20	1.2	12/81	41	21	1.1
4 AR907	2/81	86	30	1.1	60	20	1.2	12/81	42	20	1.1
8 AR907	2/81	110	22	1.3	60	20	1.2	12/81	60	21	1.2
3 CEF54	8/80	109	28	1.2	60	22	1.2	3/81	50	23	1.2
3 PSSF	8/81	75	21	1.3	60	20	1.2	12/81	69	20	1.3
5 CEF61	8/81	116	31	1.1	60	22	1.2	8/82	62	22	1.1
1 CEF54	8/80	99	31	1.1	50	16	1.2	4/81	28	17	1.1
1 PSSF	8/81	75	22	1.3	50	16	1.2	3/82	56	16	1.3
8 CEF61	8/81	100	20	1.1	50	17	1.2	8/82	50	18	1.1
2 CEF54	8/80	95	32	1.2	40	10	1.2	3/81	17	13	1.2
2 PSSF	9/81	78	22	1.3	40	12	1.2	2/82	46	13	1.4
4 CEF61	8/81	101	23	1.2	40	12	1.2	8/82	40	14	1.3

[1]
Total Stand = trees > 0.5 in d.b.h.
Dmax = maximum d.b.h., in.
q = ratio of number of trees per acre in adjacent 1-in d.b.h. classes.

The sub-merchantable pine component of each stand was sub-sampled after cut using about fifty 1/100-acre plots both at the start and at the end of the growth period. These data for the seedlings (0-inch d.b.h. class) and saplings (1- through 3-inch d.b.h. classes) are given, along with target frequencies for each group, in table 3. The target 1- through 3-inch class frequencies were generated by the target B-D-q structure. The number of seedlings (0-inch class) theoretically required in the target after-cut stand were generated by multiplying the q times the number required in the 1-inch class. We regard these as theoretical minima for the sub-merchantable component. Note that only the PSSF stands had sub-merchantable tree frequencies greater than the theoretical minima after the first cut.

Initial Regulation Assignments

Assigned target structures are given in table 2 along with the actual residual structures. The prescribed structure in the CEF54 stand 3 and CEF61 stand 5 stands is essentially the one that Reynolds (1959) would prescribe as an ideal residual stand for a 5-year cutting cycle to produce sawtimber or "large" products (Farrar 1984). The AR907 and PSSF stand 3 prescribed structures are the same except that the Dmax was set 2 inches lower because of poorer sites at these locations. The UAM stand structures were prescribed to obtain information on a q smaller or larger than 1.2 and lower residual basal area. The other CEF54, CEF61, and PSSF stand structures were prescribed to obtain information o different Dmax and BA combinations aimed at producing smaller sawtimber or "medium" products (CEF54 stand 1, CEF61 stand 8, and PSSF stand 1) and mostly pulpwood or "small" products (CEF54 stand 2, CEF61 stand 4, and PSSF stand 2).

Only about half of the stands installed during 1980-81 (UAM and CEF54) had a residual basal area within ± 10 percent of the assigned residual (tabl 2) for the following two reasons:

(1) Initially, all stands were cut strictly to leave the number of trees per 1-inch d.b.h. class prescribed by the target B-D-q with the exception that deficits in larger d.b.h. classes were compensated by leaving comparable basal area in smaller classes where possible. However, several stands had initial structures with deficits in sma d.b.h. classes that could not be compensated by leaving additional basal area in yet smaller classes. This resulted in some overcutting with respect to basal area in several stands.

Figure 1 shows the d.b.h. distribution for AR90 stand 4 in 1981 and illustrates how deficits are compensated. The before-cut, target residual, and actual after-cut structures are shown along with a structure adjusted via the q to leave the specifie basal area. The trees per d.b.h. class above the adjusted after-cut line should have been removed rather than those above the actual after-cut line.

Table 3. -- Target starting and ending after-cut sub-merchantable stands, first cutting cycle [1]

Stand & location	Target after-cut stand Seedl. TPA	Target after-cut stand Sapl. TPA	Date	Start after-cut stand Seedl. TPA	Start after-cut stand Sapl. TPA	Date	End after-cut stand Seedl. TPA	End after-cut stand Sapl. TPA	Remarks
12 UAM	11	27	2/81	42	18	3/86	2,030	12	
13 UAM	11	27	2/81	0	4	3/86	1,400	28	
11 UAM	89	161	2/81	25	21	12/85	1,879	60	No end cut.
14 UAM	89	161	4/81	0	7	12/85	1,129	17	No end cut.
2 AR907	46	97	12/81	0	0	2/87	2,580	728	No end cut.
4 AR907	46	97	12/81	0	0	2/87	1,502	330	No end cut.
8 AR907	46	97	12/81	0	2	2/87	3,928	94	
3 CEF54	43	90	6/81	0	2	2/86	1,338	50	No end cut.
3 PSSF	46	97	12/81	842	380	5/87	422	102	
5 CEF61	43	90	8/82	0	4	2/88	780	10	
1 CEF54	48	101	2/81	0	4	2/86	1,088	138	No end cut.
1 PSSF	48	101	3/82	328	308	5/87	106	220	
8 CEF61	45	95	8/82	2	6	2/88	3,260	2	
2 CEF54	74	156	6/81	82	24	2/86	1,090	240	No end cut.
2 PSSF	56	117	2/82	58	250	5/87	118	34	
4 CEF61	56	117	8/82	0	0	3/88	640	2	

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[1] Seedl. = seedlings, stems > 0.5 ft tall through 0.5 in d.b.h.
Sapl. = saplings, $0.5 < \text{d.b.h.} \leq 3.5$ in.

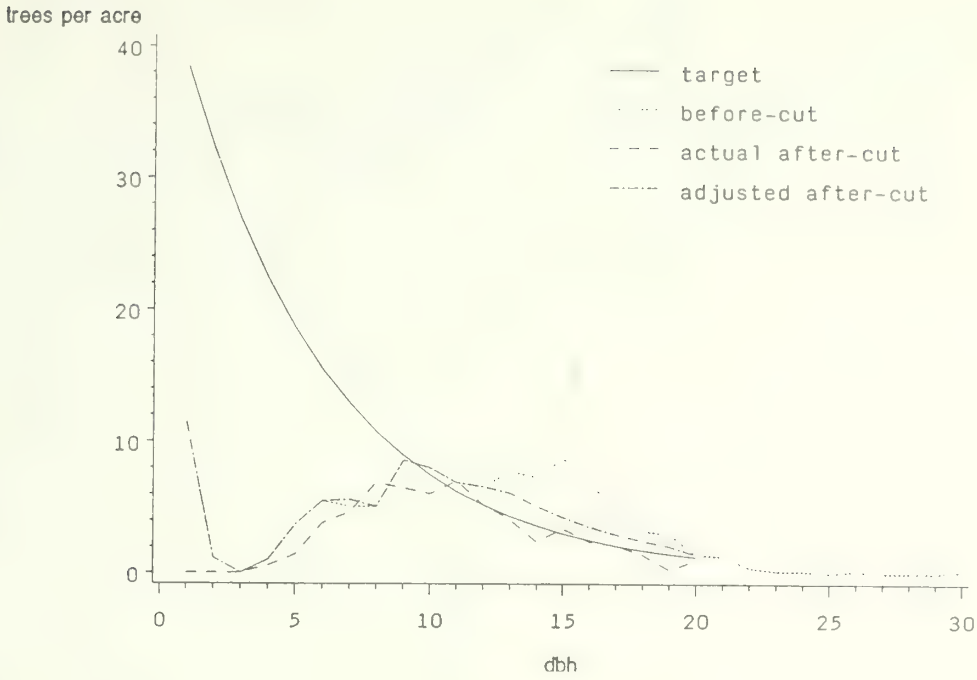

Figure 1. -- D.b.h. distributions, AR907 stand 4, 1981.

(2) Stands 1, 2, and 3 at CEF54 also had deficits resulting in some overcutting. In addition, these stands were further damaged by logging activities associated with the removal of large volumes of sawtimber per acre and by two successive windstorms. As a result, we recommend that if stands containing 10+ Mbf Doyle are to be reduced to 5 Mbf or less, allowances should be made for logging damage, and the cutting should be done as carefully as possible. If the amount of damage can be predicted, the desired residual basal area can be increased an appropriate percentage, allocated via the q, to allow for anticipated damage. Then, the removals can be made in one cut. This is the most convenient procedure and will proportionally increase the number of trees in the smaller d.b.h. classes where the greatest damage is most likely to occur. If the amount of damage cannot be safely predicted, the reduction should be made in two cuts. The second cut should occur about 2 to 3 years after the first. Each cut should remove about half of the desired harvest, with the second cut adjusted to ensure that the desired residual basal area is left.

For the stands installed during 1981-82 (AR907, PSSF, and CEF61), again only half had residual basal areas within ± 10 percent of the assigned density, but here the error tended to be toward the plus side (table 2). When the stands at PSSF and CEF61 were cut, we had begun to adjust residual density in two ways:

(1) For naturally occurring deficits, we adjusted the actual residual basal area via q to leave the assigned basal area, regardless of where the deficits or surpluses occurred. This often requires that basal area be left in d.b.h. classes larger than the classes in which the deficits occur.

(2) We also compensated for logging damage by adding 5 to 10 percent of assigned basal area, apportioned via q, to the residual structure. This allowed the CEF61 stands to be safely cut, although they had before-cut volumes and removals similar to those of the CEF54 stands (table 1).

In the AR907 stands, we had not yet adopted the above adjustments when these stands were first cut, but stand 8 here had a 1981 before-cut structure amenable to leaving the desired after-cut stand (fig. 2). A surplus of basal area was left after cutting in the PSSF stands (table 2), because much less logging damage occurred than anticipated. Skidding in these stands was done with horses.

Marking

The required number of trees per d.b.h. class to be cut is specified as the surplus above the adjusted residual targets. All trees above the Dmax were generally cut. The marking rules used to choose the other trees specified to be cut per d.b.h. class can be summarized simply as "cut the worst and leave the best." At least two, and sometimes three or four, passes over the stand were required in these research applications to find and mark all of the trees to be removed.

Cutting

The contractors who logged our study sites were instructed to minimize damage to reproduction as well as standing residual timber. There were no

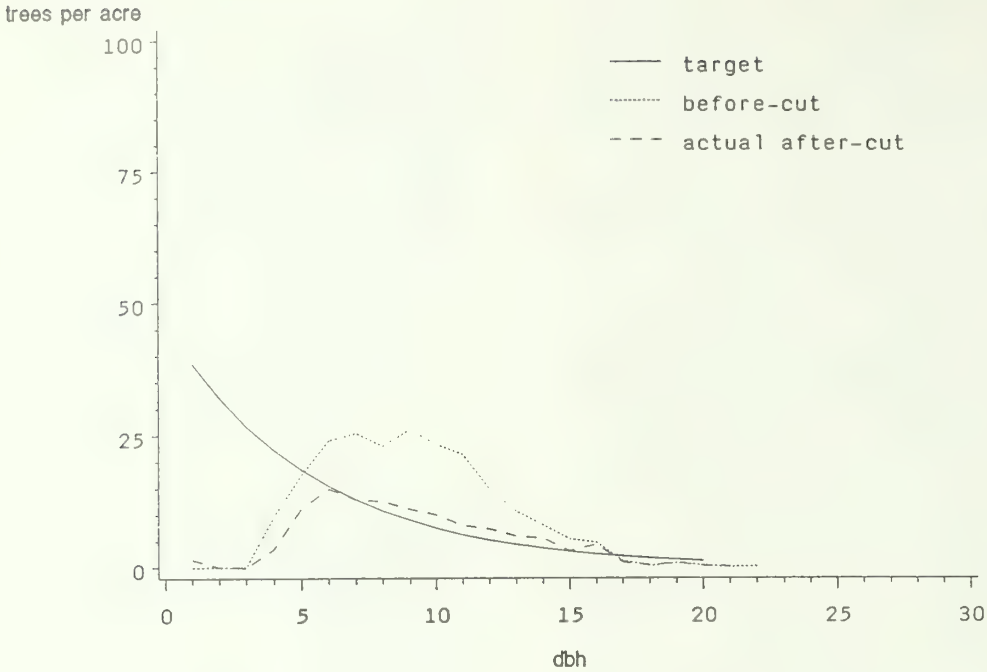

Figure 2. -- D.b.h. distributions, AR907 stand 8, 1981.

other special precautions, except log lengths were restricted to a maximum of 32 feet on the CEF. The PSSF used horse logging, which was so damage-free that most of the extra basal area left to absorb damage was not needed. The logging damage to the CEF54 stands was largely due to high standing volumes and removals, and would have been hard to avoid by any operator without resorting to some compensating procedure.

Other Cultural Operations

Essentially all hardwoods 1 inch in d.b.h. and larger in all stands were controlled by injection soon after the timber cutting was accomplished. The need for additional hardwood control should be determined at the end of each cutting cycle.

Remeasurement and Second Cut

The initial inventory procedures were repeated at the end of the first cutting cycle. Stand boundaries were retraced and painted before inventory. All boundary trees were identified to be either in or out of the stand.

The prescribed residual structures were compared with the observed before-cut structures to determine the removals in a second cut. If a stand did not have a before-cut basal area substantially exceeding the prescribed after-cut density, the stand was not cut.

RESULTS AND DISCUSSION

Merchantable Volume Growth

To obtain the most realistic value, growth over a cutting cycle was calculated as follows: final before-cut value minus initial before-cut value plus value marked for initial cut. Thus, the resulting net growth value is adjusted for any losses due to logging damage as well as mortality during the growth period plus any growth on the residual stand resulting from delays in cutting. However, it does not account for any growth on the marked stand resulting from such delays.

Table 4 gives the re-inventory results for each stand at the end of the first cutting-cycle (growth period). About half of the stands increased in basal area at an expected rate. For average sites, basal areas of 40 to 60 should grow at a rate of 2 to 3 square feet per acre per year, respectively (Murphy and Farrar 1982). The UAM stands, the PSSF stands, and AR907 stand 8 grew at these rates. In the other stands, basal area growth was reduced to 1.5 square feet or less because of overcutting, logging damage, and/or later mortality during the period. Here, mortality was the greatest problem. These stands lost 12 to 39 trees during the growth period, with the CEF54 stands suffering the greatest losses. However, most stands still grew sawtimber at a rate exceeding 200 fbm Doyle per acre per year because their losses were mostly in small trees.

Table 4. -- After-cut merchantable values and subsequent growth, first cutting cycle 1/

Stand & location	Date	After-cut stand values					YRS	Periodic annual increment				
		TPA	BA	MCF	SCF	DOYLE		TPA	BA	MCF	SCF	DOYLE
12 UAM	2/81	70	48	1,491	1,236	4,938	5	-0.2	2.0	80	80	410
13 UAM	2/81	62	49	1,571	1,331	5,387	5	-0.8	2.4	91	89	444
11 UAM	2/81	82	39	1,065	754	2,770	5	-1.6	2.4	94	96	411
14 UAM	4/81	81	40	1,106	780	2,864	5	-1.2	2.2	82	86	364
2 AR907	12/81	57	41	1,322	1,062	3,983	6	-2.3	1.2	50	56	278
4 AR907	12/81	59	42	1,333	1,031	3,678	6	-2.0	0.2	20	34	160
8 AR907	12/81	113	60	1,775	1,233	4,177	6	-2.8	2.5	111	120	528
3 CEF54	3/81	84	50	1,654	1,252	4,827	5	-6.0	0.6	55	72	307
3 PSSF	12/81	141	61	1,507	1,137	3,951	5	4.2	2.4	71	59	264
5 CEF61	8/82	117	62	2,000	1,485	5,828	6	-3.7	1.5	80	84	368
1 CEF54	4/81	48	28	908	676	2,360	5	-5.4	-0.2	28	52	231
1 PSSF	3/82	145	50	1,076	699	2,178	5	7.4	3.4	82	58	220
8 CEF61	8/82	84	50	1,614	1,184	4,070	6	-4.5	0.7	50	70	303
2 CEF54	3/81	57	17	417	130	304	5	-7.4	0.0	23	42	134
2 PSSF	2/82	146	39	687	290	733	5	1.8	1.8	57	49	153
4 CEF61	8/82	106	40	1,089	548	1,468	6	-6.5	0.7	58	80	267

1/ YRS = period length in years.

Only the PSSF stands had net increases in merchantable trees per acre. Generally, where the prescribed Dmax was 16 inches or larger and site index was 75 feet or more (table 2), the stand grew sawtimber at a rate exceeding 250 fbm Doyle and up to over 500 fbm. One of the stands with a 12-inch Dmax (CEF61 stand 4) had a Doyle growth rate exceeding 250 fbm, but this was due largely to sawtimber ingrowth on this good site.

Regeneration

As a minimum, the residual target structures would call for about 40 to 250 sub-merchantable trees (0- through 3-inch d.b.h. classes) per acre. On this basis, from table 3 it appears that adequate reproduction is being secured in most of the stands after the second cut. The exceptions are the three CEF61 stands. These stands were the last ones treated in 1982 and did not have the average and above average seed crops of 1980 and 1981, respectively, as did the stands in CEF54. Instead, they initially had the poor seed crop of 1982. Thus, the CEF61 stands have developed very few saplings so far but do have ample stands of seedlings resulting from seed crops after 1982. The usual high reproductive rate for loblolly in that area is typified by the reproduction on the CEF54 stands. Adequate sapling development is therefore anticipated for the CEF61 stands.

Residual Stands and Second Cut

All stands, except CEF54 stand 1 and stand 2, had grown in basal area and were near or had exceeded their prescribed residual levels at the end of the first cutting cycle (table 5). CEF54 stand 1 may recover in another 5 years, but CEF54 stand 2 will probably require 10 years or more to recover. This points up the desirability of ensuring that the prescribed residual density is left through careful cutting and allowances for logging damage. In most cases where cutting was done (table 5), the Dmax was left at or very close to that specified, but the residual q was as specified in only six of the stands. In the rest of the stands, the q will generally be achieved only after regeneration has developed sufficiently to fill in the deficiencies largely present in the smaller d.b.h. classes. This may require two or more additional 5-year cutting cycles. Even then the actual q may fluctuate ± 0.1 or so because of logging damage, periodic mortality, and irregularities in regeneration and recruitment.

The nine stands that were initially left at or near their prescribed densities (table 2) developed such that they could be operably cut again at the end of the cycle to leave their prescribed densities (table 5). The residual density of each cut stand was within 10 percent of that assigned, and all but one were within 5 percent. As a graphic example, figure 3 shows the before-cut, target residual, and actual after-cut d.b.h. distributions for AR907 stand 8 in 1987.

In all cases but two, the second cuts were operable for sawtimber if 1,000 fbm Doyle per acre is the minimum acceptable volume (table 6) . In the two cases where the sawtimber cut was less than 1,000 fbm (CEF61 stand 4 and PSSF stand 2 "small products" stands), the merchantable cubic-foot

Table 5. -- Before-cut, target, and actual after-cut structures at end of first cutting cycle, total stand

Stand & location	Date	Before-cut structure			Target after-cut atructure			Actual after-cut structure			
		BA	Dmax	q	BA	Dmax	q	Date	BA	Dmax	q
12 UAM	12/85	59	25	1.1	50	22	1.1	3/86	49	22	1.1
13 UAM	12/85	60	24	1.1	50	22	1.1	3/86	48	22	1.1
11 UAM	12/85	53	24	1.2	50	22	1.3	12/85	53	24	1.2
14 UAM	12/85	51	23	1.1	50	22	1.3	12/85	51	23	1.1
2 AR907	2/87	53	23	1.2	60	20	1.2	2/87	53	23	1.2
4 AR907	2/87	51	23	1.1	60	20	1.2	2/87	51	23	1.1
8 AR907	9/86	79	23	1.2	60	20	1.2	2/87	61	20	1.2
3 CEF54	2/86	56	23	1.1	60	22	1.2	2/86	56	23	1.1
3 PSSF	11/86	73	22	1.3	60	20	1.2	5/87	62	20	1.2
5 CEF61	8/87	73	24	1.2	60	22	1.2	2/88	61	23	1.1
1 CEF54	2/86	30	19	1.1	50	16	1.2	2/86	30	19	1.1
1 PSSF	10/86	67	19	1.3	50	16	1.2	5/87	55	16	1.2
8 CEF61	8/87	56	21	1.1	50	17	1.2	2/88	49	19	1.1
2 CEF54	2/86	22	18	1.4	40	10	1.2	2/86	22	18	1.4
2 PSSF	10/86	50	15	1.4	40	12	1.2	5/87	40	12	1.1
4 CEF61	8/87	46	16	1.2	40	12	1.2	3/88	39	13	0.9

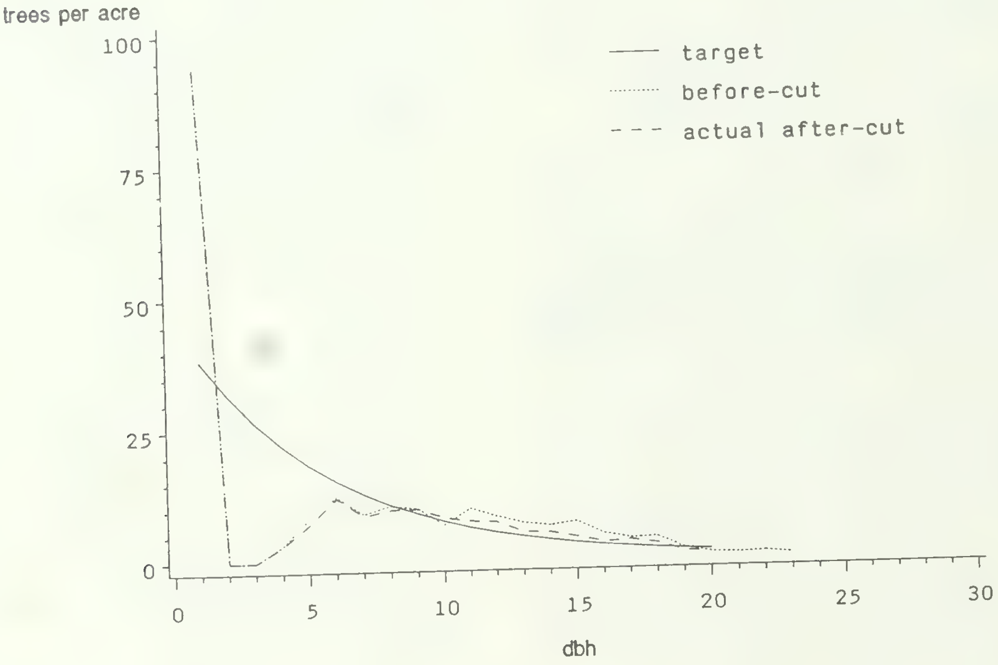

Figure 3. -- D.b.h. distributions, AR907 stand 8, 1987.

Table 6 -- Before-cut merchantable values and proposed removals at end of first cutting cycle

Stand & location	Date	Before-cut stand values					Values marked for cut				
		TPA	BA	MCF	SCF	DOYLE	TPA	BA	MCF	SCF	DOYLE
12 UAM	12/85	70	59	1,899	1,635	6,927	5	9	336	318	1,475
13 UAM	12/85	63	60	1,971	1,732	7,366	5	10	391	375	1,821
11 UAM	12/85	86	52	1,541	1,216	4,733	0	0	0	0	0
14 UAM	12/85	81	51	1,493	1,167	4,493	0	0	0	0	0
2 AR907	2/87	55	49	1,647	1,390	5,574	0	0	0	0	0
4 AR907	2/87	55	49	1,670	1,420	5,486	0	0	0	0	0
8 AR907	9/86	114	79	2,528	2,007	7,494	14	17	620	574	2,321
3 CEF54	2/86	76	56	1,936	1,569	6,273	0	0	0	0	0
3 PSSF	11/86	165	73	1,839	1,407	5,153	22	13	372	333	1,297
5 CEF61	8/87	111	73	2,472	1,963	7,985	7	12	482	461	2,194
1 CEF54	2/86	41	29	1,004	811	2,988	0	0	0	0	0
1 PSSF	10/86	186	67	1,496	999	3,321	54	17	392	290	1,104
8 CEF61	8/87	78	56	1,917	1,543	5,643	3	6	229	220	1,043
2 CEF54	2/86	51	21	576	278	776	0	0	0	0	0
2 PSSF	10/86	163	50	991	551	1,528	23	12	300	253	783
4 CEF61	8/87	95	46	1,406	914	2,719	7	7	268	244	863

volume cut was operable if 3 cords per acre (assuming a conversion of 80 cubic feet, inside bark, per cord) is an acceptable minimum.

OBSERVATIONS

Regulation

As a result of our experience in the initial cuts, when putting these stands under B-D-q regulation, we would prescribe the following general procedure and priorities:

(1) Always leave the prescribed residual basal area whether or not the Dmax and/or q specifications can be met. The growing stock level is very important and must be adequate. As a general rule, allow about 5 to 10 percent of the residual target basal area as an additional buffer to absorb logging damage and subsequent mortality. It is better to leave slightly too much basal area than too little.

(2) Then, try to remove all trees in and above the Dmax as required by the B-D-q structure while ensuring that the specified residual basal area is left. In some cases, this may require leaving some trees above the Dmax to meet the basal area requirements.

(3) With the basal area requirement met and Dmax requirement met as well as possible, then cut in each d.b.h. class as prescribed by these constraints and the B-D-q structure so that the specified q will be approached as closely as possible. The q is the e factor least likely to be met initially because most cases the stands are deficient in the small b.h. classes. It will be approached only through time, as continued cutting and regeneration produce the required frequencies in the smaller sizes.

Application of the above three principles requires some iterative work with pencil and paper to accomplish the desired adjustments but the work can be quickly and easily done with a simple hand calculator.

Inventory and Marking

It is obvious that 100-percent inventories and the several passes made in marking the cut for research purposes are not operationally feasible for larger areas. A 5- to 10-percent cruise using fixed area plots, say 1/10-acre, to obtain good d.b.h. frequency information should provide a satisfactory inventory of the merchantable stand for management purposes. The cruise should include an assessment of the sub-merchantable stand, which can be accomplished with smaller plots nested within the merchantable inventory plots. A circular 1/100-acre plot to inventory the 1- through 3-inch d.b.h. saplings could be imposed at the center of each merchantable inventory plot, and a circular milacre (or cluster of milacres) on which to inventory the 0-inch d.b.h. seedlings could also be superimposed at the common plot center. The sub-merchantable stand inventory is important and should not be ignored. Regeneration and recruitment into larger sizes are essential to the selection system, and this component must be monitored so that remedial action can be taken if minimum levels of sub-merchantable trees are not maintained.

Marking for cut can be accomplished satisfactorily in one pass through the stand (Marquis 1978) by breaking the stand into, say, quarters; by breaking the marking d.b.h. tally into, say, four broad merchantable categories - pulpwood, small sawtimber, medium sawtimber, and large sawtimber; and by pre-posting the desired number of trees to be cut by merchantable category in each stand quarter on the marking tally sheet. Then, when marking, an effort is made to hit the marking targets in each stand quarter. If some under- or over-marking occurs, compensation is made in the next quarter. In marking, it is very helpful to have made a sketch map during the inventory that shows logical divisions of the stand (roads, streams, etc.) and any concentration of pulpwood or sawtimber volume. The marking resulting from such a procedure will be operationally acceptable.

Cutting

Cutting should be done by operators skilled in working on small tracts and who are careful to minimize damage to residual stands. They should use the smallest equipment suitable for the job. Salvage logging crews employed by many industries are often ideal. In any case, we think it is wise to generally allow about an extra 5 percent in basal area as insurance against logging losses. If needed, it is available to compensate for damage and mortality. If not needed, the little extra growing stock does not cause the serious problems generated by deficits.

Hardwood Control

The stands will likely need to be treated to control hardwoods about every 10 years. This would probably be done best with an economical selective herbicide spray applied with ground or aerial equipment. The second best treatment would be tree injection. Prescribed burning may have some limited use in selection management, say at the end of each cutting cycle to improve visibility for timber marking and logging, but is unlikely to be a main hardwood control treatment. It probably cannot be applied often enough and with sufficient intensity to be as effective as it is in even-aged stands because of the need to preserve pine regeneration and the patchy nature of the pine needle fuels in selection stands.

Possibly, a minor component of merchantable hardwoods can be managed along with the pine in sufficient quantity to be operationally cut, say, every 20 years or so. However, this will bear investigation because the density of the hardwood growing stock will probably exist largely at the expense of the pine growing stock, not in addition to it. The overall stand density "window" for an adequate selection system in loblolly/shortleaf pine seems restricted from about 45 BA at the start of a 10-year cutting cycle to about 75 BA at the end of any cycle. The residual basal area depends on the growth rate, cutting cycle, and site quality. Pine growth rates of 2.5 to 3 square feet per year seem required for suitable production on medium or better sites, which leaves little room for hardwood development. Further, hardwoods are more serious competitors with pine seedlings than are larger pines, which makes their presence even more of a detriment to development of pine regeneration and recruitment into larger size classes.

CONCLUSION

Our initial experience with B-D-q regulation during one cutting cycle shows that where stands are left reasonably close to the targets, the resulting stand growth and development of reproduction will be satisfactory. Thus, this method of regulation is apparently entirely feasible in uneven-aged loblolly/shortleaf pine stands, particularly for the structures similar to those proposed by Reynolds (1959). However, these structures and those prescribed to evaluate different combinations of B, D, and q will bear further monitoring to see how they develop and perform through time. The method does have the major advantage over the "volume - guiding d.b.h. limit" method of being objectively applicable throughout the merchantable d.b.h. range.

The major advantages of using a selection syster in general are low capital outlays, facility for quickly rendering small areas into a fully regulat condition, regular periodic production of operable cuts of mostly high-value sawtimber, and development of stands that are not as vulnerable a even-aged stands to most of the natural hazards faced at different stages in the development of th latter. The major disadvantages are that adequate inventory is essential, periodic hardwood control is required, and the system appears to be complicated to the uninitiated. The need for periodic hardwood control cannot be avoided and must be anticipated. But, as one gains experience with B-D-q regulation, its fundamental simplicity becomes apparent. Also, as one becomes skilled in its application, and as stand structures become more balanced and periodic growth more predictable, it may be possible to make acceptable cuts every cutting cycle and conduct inventories every other cutting cycle. However, just as repeated cyclical cutting is essential to maintain selection structures, adequate periodic inventorie are essential to monitor and control the structure to provide periodic operable cuts in perpetuity.

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Hardwood Regeneration

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GROWTH OF OAK, ASH, AND CHERRY REPRODUCTION FOLLOWING OVERSTORY THINNING AND UNDERSTORY CONTROL IN UPLAND HARDWOOD STANDS OF NORTHERN ARKANSAS[1]

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Abstract.--A study of reproduction growth following overstory thinning and understory control in mixed upland hardwood stands was initiated in the Boston Mountains of Arkansas in the spring of 1980. Thirty-six plots representing mature upland hardwood stands on medium- to high-quality sites were thinned to residual overstory densities of 40- to 60-percent relative stocking density. Subcanopy stems were partially or completely controlled with herbicide applications. Growth of oak (Quercus alba L., Q. velutina Lam., and Q. rubra L.), white ash (Fraxinus americana L.), and black cherry (Prunus serotina Ehrh.) reproduction was monitored for 5 years following treatments. Before treatment, total oak, ash, and cherry reproduction averaged 3,000 stems per acre with a mean height of less than 1 foot, and there were fewer than 10 stems per acre taller than 5 feet. After treatment, growth of oak reproduction increased with the intensity of understory control, while ash and cherry grew best under the 40-percent overstory stocking treatment.

INTRODUCTION

Mixed oak types occupy most of the commercial forest land in northern Arkansas, and oaks are the dominant timber species throughout this region. Valuable, fast-growing species such as yellow-poplar (Liriodendron tulipifera L.) do not occur in western Arkansas, and desirable species such as black walnut (Juglans nigra L.), black cherry (Prunus serotina Ehrh), and white ash (Fraxinus americana L.) occur only sporadically, primarily on the better sites. Most associated species in these upland stands are either slower growing or of lower value than the oaks, so it is important to insure that oaks will be a significant component of new stands following harvest.

Research has shown that the oak component of oung hardwood stands will depend on sprouts from ut overstory stems and the number and size of oak advance reproduction present at the time of overstory removal (Sander 1971, 1972). Newly established oak seedlings and small advance reproduction grow too slowly to compete successfully following harvest (Sander and Clark 1971; McQuilkin 1975). However, large oak advance reproduction grows rapidly after harvest and has a greater probability of becoming dominant in the new stand (Carvell 1979; Sander 1972; Sander and others 1984).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have several thousand stems per acre of oak and other desirable species that are less than 1 foot tall, but large reproduction, especially oak, is sparse or absent. Many of these stands are within 30 years of rotation age, and fully stocked, and have well-developed understories composed of tolerant noncommerical species. Given the present size and status of existing reproduction, the new reproduction stand following overstory removal will contain a mixture of species but will almost certainly contain a low proportion of oak. To enhance development of established oak advance reproduction in such stands, a shelterwood system (Sander 1979, 1983; Loftis 1983, 1985; Gottschalk 1983) with light to medium overstory removals and partial to complete understory control is being evaluated for upland oak stands in several geographic areas.

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In this paper, the 5-year height growth response of oaks (northern red (Quercus rubra L.), black (Quercus velutina Lam.), and white (Quercus alba L.), black cherry, and white ash advance reproduction are related to overstory and understory density control in mature upland hardwood stands in the Boston Mountains of northern Arkansas.

METHODS

Six stands of mature upland hardwoods were chosen for this study from Ozark National Forests lands in the Boston Mountains of northern Arkansas. Three stands were located on upper north- or east-facing slopes representing medium oak sites (50-year site index = 60 ft for northern red oak), and three stands were located on north- or east-facing mountain benches representing excellent oak sites (50-year site index >75 ft for northern red oak). Six plots (approximately 1 acre in size) were established in each stand, and one of six overstory-understory treatments was randomly assigned to each plot. Overstory (stems $\geq$1.6 inches in d.b.h.) densities were thinned to either 40 percent or 60 percent relative stocking density (Gingrich 1967). Understory (stems <1.6 inches in d.b.h.) treatments were: (1) treat all nondesirable stems, (2) treat all nondesirable stems taller than 5 ft, or (3) no understory treatment. Desirable species were oaks, ash, cherry, and black walnut.

Pretreatment overstory stocking densities for all plots averaged 106 percent with a mean basal area of about 118 ft^2 per acre (table 1). Overstory density treatments were accomplished by thinning mostly from below. All subcanopy stems 1.6 inches and larger in d.b.h. were removed first, then the overstory canopy was thinned to the prescribed stocking goal. Stumps of all nondesirable overstory stems were treated with a herbicide spray (2,4-D + picloram) immediately after felling to reduce sprouting. Overstories on all plots were predominantly oak. Northern red, black, and white oaks accounted for more than 80 percent of the overstory before thinning and more than 90 percent after treatment. Ash and cherry represented less than 1 percent of the stocking on all plots.

Understories on study plots were well developed and consisted of tolerant brushy or less desirable species such as red maple (Acer rubrum L.), serviceberry (Amelanchier arborea (Michx. f. Fern.), redbud (Cercis canadensis L.), and blackgum (Nyssa sylvatica Marsh.) on medium sites, while dogwood (Cornus florida L.), hophornbeam (Ostrya virginiana (Mill.) K. Koch), pawpaw (Asimina triloba (L.) Dunal), and sugar maple (Acer saccharum Marsh.) were common on good sites. Understory control treatments were accomplished by cutting all stems near ground level and spraying all stumps with herbicide (2,4-D + picloram) immediately after cutting. Understory treatments were completed in May 1980 and overstories were thinned in June and July of 1980.

Reproduction was measured on a series of sixteen 1/735-acre circular subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all regeneration up to 1.5 inches in d.b.h. was tallied by species, origin (true seedling, seedling sprout, or sprout from a cut stem), and total height. For all oak, ash, and cherry reproduction, stem age, basal diameter to the nearest 0.1 inch and total height to the nearest 0.1 ft were also recorded. Reproduction was measured before treatment and after the first, third, and fifth years following treatments.

The study design was a randomized block. Data were analyzed using analysis of variance to test for differences in main effects. Duncan's multiple range tests were used to compare individual treatment means.

RESULTS

Advance Reproduction Before Treatement

The pretreatment height distribution of advance reproduction on study plots is typical of nonthinned mature upland oak stands in the Boston Mountains (table 2). Total oak, ash, and cherry

Table 1.--Stand characteristics per acre before and after treatment for trees 1.6 inches and larger in d.b.h.

Stocking treatment	Original Stand			Residual Stand		
	Number of trees	Basal area	Stocking	Number of trees	Basal area	Stocking
		ft.^{2}	percent		ft.^{2}	percent
Site index = 60 ft						
40 percent	464	118	108	57	52	40
60 percent	413	121	108	82	73	60
Site index = 75 ft						
40 percent	413	114	103	54	53	40
60 percent	424	118	106	70	74	59

Table 2.--Mean height distribution per acre of oak, ash, and cherry reproduction stems before treatment

Species	Height class (feet) <1.1	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	>5.0
	number of stems					
Site index = 60						
Oaks[1/]	1959	106	15	13	5	0
Ash and cherry	930	222	143	72	41	5
Other species	4341	2910	1346	1187	905	1569
Site index = 75						
Oaks	1243	61	18	8	5	0
Ash and cherry	452	179	74	38	31	5
Other species	4813	2387	1523	1153	1160	1408

1/White, black, and northern red oaks.

reproduction and advance reproduction taller than 1 ft are greatest on the less productive upland sites. Although the number of oak reproduction stems are high, tall advance reproduction (>5 ft) is often sparse or absent. Most of the oak reproduction is less than 1 ft tall, and few stems are taller than 2 ft. Ash and cherry reproduction is highly variable throughout the Boston Mountains but is usually most abundant on medium to good sites. Although ash and cherry are minor components of the overstory in most stands, they represent the majority of the desirable species' advance reproduction taller than 2 ft (table 2).

The other species group (table 2) is dominated by the tolerant, brushy, and noncommercial species, but also includes the hickories (Carya spp.) and other less common species that would be considered acceptable for stocking on selected sites.

Reproduction After Treatment

Effects of Site Index.--Neither abundance, growth, nor mortality of pretreatment advance reproduction over the 5-year period was significantly related to site quality. The amount and survival of new reproduction was not influenced by site index either.

Effects of Overstory Density.--While total oak, ash, and cherry reproduction and number of stems taller than 1 ft increased following thinning, there was very little difference between the 40-percent and 60-percent stocking treatments. After 5 years, oak stems <1.1 ft were greater in stands thinned to 60 percent stocking, but number of stems in the 1.1 to 5.0 and over 5 ft height classes were about the same for each stocking treatment (table 3). Stands thinned to 40 percent stocking produced significantly more ash and cherry stems in the 1.1 to 5.0 and over 5 ft height classes than stands thinned to 60 percent.

While the number of oak, ash, and cherry reproduction increased following thinning, the actual number of stems is small when compared to the increase in competing stems of other species. Stems of other species taller than 1 ft increased from about 8,000 per acre before thinning to 12,000 to 15,000 per acre in 5 years. Stands thinned to 40-percent stocking produced significantly more large competing stems of other species (table 3).

Effects of Understory Control.--Understory control significantly increased the number of oak stems in the 1.1 to 5.0 and over 5 ft height classes, but there was no difference between the complete control and partial control treatments (table 3). Ash and cherry reproduction did not respond to understory control. Although there was a slight increase in the number of stems over 5 ft in height with the complete and partial control treatments, differences between the control and noncontrol treatments were not significant.

Effects of understory control on competing stems, after 5 years, is only apparent in the numbers of large stems. The number of large competing stems decreased significantly with increasing intensity of understory control (table 3).

New Reproduction.--Establishment of new reproduction after treatment was erratic and varied greatly among stands and plots within stands. Although some new oak seedlings were inventoried during each remeasurement, most of the new reproduction for northern red and black oaks resulted from the 1980 acorn crop. Five-year oak seedling establishment ranged from 200 to 6,000 per acre and averaged 1,250 seedlings per acre. The amount of new oak reproduction was not related to site index, overstory density, or understory control treatments.

Table 3.--Reproduction 5 years after treatment as affected by site index, residual stocking, and understory treatment

Species and height	Pretreatment	Site index (feet)		Residual stocking (percent)		Understory treatment		
		60	75	40	60	1[1]	2	3
----feet----	----number of stems----							
Oaks[2]								
<1.1	1601	1642a[3]	2273a	1630a	2385b	2000a	2094a	1778a
1.1-5.0	115	378a	446a	349b	475a	529b	500b	208a
>5.0	0	41a	26a	44a	28a	46b	50b	12a
Ash and cherry								
<1.1	691	513a	413a	463a	463a	424a	407a	560a
1.1-5.0	400	866a	644a	900b	614a	738a	705a	822a
>5.0	5	279a	147a	271b	155a	247a	242a	150a
Other species								
<1.1	4577	3163a	2717a	2413a	3470a	2940a	2884a	3000a
1.1-5.0	6286	9411a	9966a	10024a	9352a	8290a	10990a	9784a
>5.0	1488	3991a	3420a	4450b	2961a	1533a	3828b	5755c

[1] 1 = All stems treated; 2 = Stems >5 ft treated; 3 = No treatment.

[2] White, black, and northern red oaks.

[3] Site index, stocking, or understory treatment means in rows followed by the same letter are not significantly different at the 0.05 level.

New ash and cherry reproduction was much lower than oak, averaging about 340 seedlings per acre, and was not influenced by site quality or thinning treatments.

Mortality.--Mortality of advance oak, ash, and cherry reproduction occurred throughout the 5-year period following treatment, but the greatest losses were associated with the severe drought of 1980. More than half the small oak stems (<1.1 ft) and 20 percent of the large oak reproduction died in the 5 years following treatment. About two-thirds of the mortality occurred during the first year. Mortality for new oak reproduction averaged only about 5 percent. First-year mortality for small oak reproduction was greatest under stands thinned to 40-percent stocking, but there were no differences in mortality levels between stocking treatments for the 5-year period. Understory control did not influence mortality of oak reproduction.

Losses of ash and cherry reproduction were much lower than for the oaks. About 20 percent of the small ash and cherry reproduction and only 8 percent of the large stems died after treatment. All of the new ash and cherry reproduction survived. Mortality of the ash and cherry reproduction was not influenced by the overstory or understory treatments.

Height Growth After Treatment

Oak, ash, and cherry seedlings established after treatments produced the greatest height growth in stands with all competing stems removed (table 4). Seedlings in stands thinned to 40 percent stocking were also slightly taller and had larger stem diameters than seedlings in stands at 60-percent stocking, but the differences were not significant.

Table 4.--Total height of new oak, ash, and cherry seedling reproduction established after treatment

Stocking treatment	Understory treatment		
	1[1]	2	3
	----feet----		
Oaks[2]			
40-percent stocking	0.85c[3]	0.74b	0.55a
60-percent stocking	0.78b	0.58a	0.53a
Ash and cherry			
40-percent stocking	1.11b	0.83a	0.70a
60-percent stocking	0.97b	0.76a	0.70a

[1] 1 = All stems treated; 2 = Stems >5 ft treated; 3 = No treatment.

[2] White, black, and northern red oaks.

[3] Means in rows followed by the same letter are not significantly different at the 0.05 level.

Net height growth of oak advance reproduction established prior to treatment was relatively small, but varied significantly with initial size, overstory density and intensity of understory control (table 5). Small oak reproduction (<1.1 ft) grew best in stands thinned to 40- or 60-percent stocking where all competing understory stems had been removed, but the increase in height averaged only about 0.5 ft in 5 years. Larger oak reproduction responded to overstory density and intensity of understory

Table 5.--Net 5-year height growth of pretreatment oak, ash, and cherry reproduction

Stocking treatment	Understory treatment					
	Stems <1.1 feet			Stems >1.1 feet		
	1[1]	2	3	1	2	3
	feet					
Oaks[2]						
40-percent stocking	0.55b[3]	0.27a	0.27a	1.33c	0.82b	0.63a*[4]
60-percent stocking	0.43b	0.25a	0.20a	1.05c	0.72b	0.26a
Ash and cherry						
40-percent stocking	2.45b	2.50b	1.73a*	3.57b	3.72b	3.04a*
60-percent stocking	1.73a	1.72a	1.73a	2.87a	2.60a	2.34a

[1] 1 = All stems treated; 2 = Stems >5 ft treated; 3 = No treatment.

[2] White, black, and northern red oaks.

[3] Stems <1.1 or stems >1.1 means in rows followed by the same letter are not significant at the 0.05 level.

[4] * = Stocking treatment significant at 0.05 level.

control. Best height growth occurred in stands thinned to 40-percent stocking with complete understory control averaging 1.3 ft. Poorest growth, averaging 0.3 ft, was associated with overstory densities of 60 percent and no understory control.

Ash and cherry reproduction grew best in stands thinned to 40-percent stocking with either partial or complete control of competing understory stems (table 5). Height of small ash and cherry reproduction increased by about 2.5 ft while larger stems grew more than 3.5 ft over the 5-year period.

DISCUSSION

The primary objective in applying the shelterwood method in mature upland oak stands is to develop a sufficient amount of oak advance reproduction that can compete successfully following overstory removal. This may be accomplished through establishment and growth of new seedlings and/or enhanced development of small established stems. In this study, all overstory and understory density control treatments increased the average size of oak, ash, and cherry reproduction. The number of oak stems taller than 1 ft increased from about 100 per acre before treatment to more than 500 per acre in stands with partial or complete understory control. The number of ash and cherry stems taller than 1 ft increased by 400 to 800 per acre after thinning. Most of the increase resulted from smaller pretreatment stems and new reproduction growing into the 1.1- to 3.0-ft height classes (table 6). Most of the oak reproduction taller than 5 ft developed from stump sprouts, primarily in stands where the site index was 60 ft. Only about 20 stump sprouts per acre were observed in the stands where site index was 75 ft. Graney and Rogerson (1985) reported that stump sprouts would be a minor component of the oak regeneration on good Boston Mountain sites after harvest. Based on prethinning diameter distributions for oak growth and yield plots representing 70- and 80-year-old stands where site indexes were 70 and 80 ft, predicted stump sprouting (Sander and others 1984) for black, northern red, and white oaks would average fewer than 40 per acre. Therefore, development of small oak reproduction into the larger size classes will be required to maintain a significant oak component in future stands.

Ash and cherry reproduction taller than 5 ft developed from older seedlings and seedling sprouts. Ash and cherry stump sprouts, though few in number, averaged nearly 3 ft in height growth per year, and some stems exceeded heights of 20 ft after 5 years. Ash and cherry seedling sprouts and stump sprouts were the dominant reproduction in stands receiving understory control treatments.

Although overstory and understory treatments imposed in this study resulted in substantial increases in the number of oak, ash, and cherry stems taller than 1 ft, the average 5-year increase in height for established reproduction, particularly oaks, was relatively small. Small oak reproduction averaged only about 0.1 ft of height growth per year, while larger oak stems grew about 0.2 to 0.3 ft per year under thinned stands with little or no initial competition from understory stems. Ash and cherry heights increased by an average of 2.5 to 3.5 ft over the 5 years after treatments, with many stems exceeding 10 ft in total height.

The rather small 5-year net height increase observed for oak reproduction in this study may not be indicative of the possible long-term growth responses to the overstory and understory density control treatments. The severe drought of 1980 affected reproduction of all species, but the impact on the oaks was very pronounced. More than half the small oak reproduction was lost to mortality due to the drought, and most of the

Table 6.--Mean height distribution of reproduction stems per acre in stands prior to treatment and 5 years after understory treatment

Understory treatment	Height class (feet)					
	<1.1	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	>5.0
	-----------------	-----------------	number of stems	-----------------	-----------------	-----------------
Oaks[1]						
Pretreatment	1601	84	16	10	5	0
1[2]	2000	409	66	25	29	46
2	1865	395	51	15	39	50
3	1778	170	20	4	14	12
Ash and cherry						
Pretreatment	691	200	108	51	36	5
1	424	315	177	172	74	247
2	208	302	161	154	88	242
3	560	285	275	150	112	150
Other species						
Pretreatment	4577	2648	1435	1170	1033	1488
1	3493	3278	2296	1750	966	1533
2	2858	3822	2920	2462	1786	3828
3	2250	2940	2844	2392	1608	5755

[1] White, black, and northern oaks.
[2] 1 = All stems treated; 2 = Stems >5 ft treated; 3 = No treatment.

surviving stems died back and resprouted during the first 3 years following treatment. Maximum height growth for oak reproduction occurred the fourth and fifth years after treatment. If this growth trend continues through the tenth growing season, stands receiving the complete understory control treatments should produce a significant increase in large oak stems taller than 5 ft.

Establishment of new oak, ash, and cherry reproduction after treatment was highly variable and was not affected by overstory or understory treatments. However, development of the new reproduction was strongly influenced by understory competition. In stands with all competing stems controlled, oak, ash, and cherry seedlings were significantly taller and had larger tops and signficantly larger stem diameters than seedlings in stands with partial or no understory control.

In stands thinned to 60-percent stocking, complete understory control treatment remained effective through the fifth year after treatment, with most oak, ash, and cherry reproduction either free-to-grow or subject to light-to-moderate competition. Although there was rapid development of competing understory between the second and fifth years, most are single stems and less than 5 ft tall. Ash and cherry are the only reproduction stems taller than 10 ft.

Understory control in stands thinned to 60-percent stocking should remain effective for an additional period of time as overstory canopies expand and slow the development of competing understory species. Mortality in residual stands due to the 1980 drought or other causes resulted in lower overstory densities than desired and could have contributed to the rapid development of competing understory stems in the stands thinned to 60-percent stocking.

Complete understory control in stands thinned to 40-percent stocking was effective through the fifth year, but most of the small oak reproduction will soon be overtopped by competing species. Under the relatively open conditions of the 40-percent treatment, development of the competing understory is rapid, and by the fifth year more than 4,000 stems per acre were taller than 5 ft. The competion problem under heavily thinned stands was compounded by a surge of herbaceous vegetation and vine development, especially in stands where the site index was 75 ft. In these stands, the slower growing oak reproduction will be affected more by the increased competition. Ash and cherry reproduction are growing as well or better than competing stems. Sassafras (Sassafras albidum (Nutt.) Nees) and black locust (Robinia pseudoacacia L.) were abundant after 5 years in stands where all nondesirable stems had been treated, although these species were rare or absent in pretreatment inventories. Pawpaw is also a major component in the understories on the better sites. The remainder of the new understories developing after treatment were mainly the same species that were present before treatment and developed from smaller seedlings or seedling sprouts from stems cut but not killed by the herbicide treatment. Multiple stem sprouts from stumps of larger cut stems were absent in every stand where all nondesirable stems had been treated.

The partial understory control treatment significantly increased growth of oak, ash, and cherry reproduction, but the effects of this treatment will probably not extend beyond the fifth year as residual understory stems continue to develop. Understory development is most pronounced under stands thinned to 40-percent stocking where all small oak stems and most of the larger stems are now overtopped by competing stems. Only ash and cherry have maintained a favorable competitive advantage in stands receiving the partial control treatment.

Growth of desirable reproduction was poorest in stands where understories were not treated. Height growth for most oak reproduction averaged less than 0.3 ft in 5 years. Only large oak stems in the heavily thinned stands grew more than 0.5 ft over the 5-year period. Ash and cherry reproduction grew slower under the noncontrol treatment, but still produced height increases of 2 to 3 feet, which was greater than oak reproduction growth for all overstory and understory treatments.

CONCLUSIONS

The shelterwood method, combined with adequate understory control, should be an effective system to enhance development of established desirable reproduction in upland oak stands in the Boston Mountains. The number of oak, ash, and cherry stems taller than 1 ft was significantly greater in thinned stands where competing understory stems were controlled with herbicides. Ash and cherry produced a greater response to overstory and understory treatments than the oaks. Although understory control produced the greatest growth response in stands thinned to 40-percent overstory stocking, development of competing understory stems will soon overtake the slower growing oak reproduction. Only ash and cherry will compete successfully with nondesirable understory stems. Maintaining an overstory density of 60 percent or more will result in slower growth of desirable reproduction but should discourage rapid redevelopment of competing understory stems.

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SPECIES COMPOSITION OF REGENERATION AFTER CLEARCUTTING SOUTHERN APPALACHIAN HARDWOODS[1]

David L. Loftis[2]

Abstract.--Regeneration after clearcutting of Southern Appalachian hardwood stands varies substantially in species composition not only among sites of different quality and previous-stand composition, but also among sites of similar quality and similar previous-stand composition. Severe competition from less desirable species for available growing space is common in regenerated stands. The appropriate use of clearcutting, the need for quantitative models to predict species composition after harvest cutting, and the need for alternative cultural practices are discussed.

INTRODUCTION

Over the last 2 decades, clearcutting has become a widespread practice in Appalachian hardwood forests. Some land managers, including the USDA Forest Service, have adopted clearcutting as their primary harvesting practice. At least one reason for its adoption was the perception that single-tree selection was not providing satisfactory regeneration--a perception that has been proved correct by long-term research (Della-Bianca and Beck 1985). As an even-aged alternative, the practice of clearcutting appeared promising based on historical observations (Frothingham 1931) as well as current research (Merz and Boyce 1956, McGee 1975, McGee and Hooper 1970). And, of course, the short-term economics of timber harvesting--the higher volumes per acre harvested--tend to favor clearcutting.

What kinds of stands are we creating for the future? Is species composition what we hoped it would be? The data from a small but representative sample of operational clearcuts suggest that, while new stands created by clearcutting have generally been acceptable, the results have been quite variable.

SOURCES OF REGENERATION

Species composition of a stand created by clearcutting is a function of the sources of regeneration--advance growth and the potential for new seedling establishment--present on the site at the time of clearcutting. All hardwoods can regenerate from stump sprouts, and all hardwoods can regenerate from advance reproduction when it is present. But only yellow-poplar, birches, shortleaf pine, and, in some cases, black cherry regenerate reliably from new seedlings established after a harvest cut (table 1). All other species require advance growth--either advance reproduction or rootstocks of trees larger than 2 inches d.b.h. that produce stump sprouts or root sprouts after a harvest cut.

A distinction must be made between clearcutting as a harvesting practice (the definition used in this paper), and clearcutting as a category in classifications of regeneration methods. The Society of American Foresters equates clearcutting with clean felling, "the removal of the entire standing crop" (Society of American Foresters 1971). This usage defines clearcutting in terms of harvesting. In silviculture, clearcutting as a category in classifications of regeneration methods has a more restricted meaning. The temporal arrangement of cuttings is only one criterion used to classify a regeneration method, even in the simplest classification systems. The other criterion is the origin or source of regeneration that ultimately dominates the new stand (Smith 1962). Thus, the clearcutting method of regeneration is the removal of the entire stand in one cutting with regeneration obtained from new seedlings established after the harvest cut.

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Table 1.--Regeneration sources for some Southern Appalachian tree species

Species	Shade tolerance
--Regeneration from new seedlings established after cutting--	
Yellow-poplar (Liriodendron tulipifera L.)	intolerant
Sweet birch (Betula lenta L.)	intermediate
Black cherry (Prunus serotina Ehrh.)*	intolerant
Yellow pines (Pinus spp.)	intolerant
--Advance-growth-dependent species--	
Black cherry (Prunus serotina Ehrh.)*	intolerant
Black locust (Robinia pseudoacacia L)	intolerant
Red oak (Quercus rubra L.)	intermediate
White oak (Quercus alba L.)	intermediate
Chestnut oak (Quercus prinus L.)	intermediate
Black oak (Quercus velutina Lam.)	intermediate
Scarlet oak (Quercus coccinea Muenchh.)	intermediate
White ash (Fraxinus americana L.)	intermediate
Cucumbertree (Magnolia acuminata L.)	intermediate
White pine (Pinus strobus L.)	intermediate to tolerant
Hickories (Carya spp.)	intermediate to tolerant
Basswood (Tilia heterophylla Vent.)	intermediate to tolerant
Red maple (Acer rubrum L.)	intermediate to tolerant
Sugar maple (Acer saccharum Marsh.)	tolerant
Beech (Fagus grandifolia Ehrh.)	tolerant
Buckeye (Aesculus octandra Marsh.)	tolerant
Hemlock (Tsuga canadensis (L.) Carr.)	tolerant
Dogwood (Cornus florida L.)	tolerant
Silverbell (Halesia carolina L.)	tolerant
Sourwood (Oxydendrum arboreum (L.) DC)	tolerant

* Black cherry, in some cases, does regenerate from new seedlings established after harvest; but, in many cases, regeneration appears to depend on the presence of advance reproduction.

This distinction is not trivial. It might not be reasonable to expect the public to understand it, but for the silviculturist this distinction is critically important for regeneration prescription. It focuses attention on the question that must be asked: what will be the source or sources of regeneration for the next stand?

DESCRIPTION OF STUDY AREAS

Nine sites on the Pisgah Ranger District of the Pisgah National Forest near Brevard, North Carolina, were selected for sampling. All were accessible and had developed after clearcutting 9 to 11 years ago. They are representative of the clearcuts I have examined over the years. The sites range in quality from oak site index 70 to 90 feet at age 50 years (Olson 1959), and from 2500 to 4000 feet above sea level. Sites of this quality produce the bulk of the high-quality sawtimber grown in the Southern Appalachians. In each case, the mature stands occupying these sites had been harvested in the recommended manner--the merchantable stand was cut by loggers, and all residual stems taller than 4.5 feet were felled with chainsaws.

Circular 0.01-acre plots were located 200 ft. apart on transect lines also 200 ft. apart--approximately 1 plot per acre. On each plot, all stems taller than 4.5 feet were tallied by species, 1-inch d.b.h. class, and stem origin--single-stemmed or sprout clump. The five most dominant stems on each plot were noted.

RESULTS AND DISCUSSION

Composition of the stands harvested from these nine sites follows the familiar pattern of second-growth stands in the Southern Appalachians (table 2). Oaks other than northern red oak dominated the lower quality sites (oak site index=70 feet). Northern red oak and yellow-poplar became more important on higher quality sites. Red maple and hickory were present on all sites. Ash, basswood, black cherry, sweet birch, cucumbertree, and sugar maple were present on one or more of the higher quality sites. The remaining merchantable volume consisted of beech, black locust, silverbell, hemlock, white pine, shortleaf pine, and black gum.

Table 2.--Species composition of mature stands harvested by clearcutting on nine sites in the Southern Appalachians

SITE	OAK SI	Y-P	NRO	OTHER OAKS	ASH-CHERRY CUC-BASS-SM	BIR	HIC	RM
				--Percent of total volume--				
1	90	64	10	21	1	1	1	2
2	90	16	17	53	0	1	2	7
3	90	52	7	32	1	1	1	1
4	90	35	3	39	0	1	1	10
5	80	23	25	41	1	1	2	7
6	80	35	22	27	2	1	5	6
7	80	10	52	20	5	1	3	6
8	70	2	3	79	0	0	2	2
9	70	3	4	79	0	0	3	1

Species Composition

My analysis of regeneration focuses on species composition of the 5 most dominant trees per 0.01 acre plot, excluding black locust. Crown closure has occurred. The species in a dominant crown position now, excluding black locust, are long-lived and are capable of occupying the growing space on the 0.01 acre plot through all or most of the rotation.

The variability in species composition among stands receiving the same treatment is obvious (table 3). Sites 1, 3, and 4 are equal in quality (SI=90), and the oak components in the previous stands on these sites were all about the same. Only sites 3 and 4 have an appreciable oak component in the regenerated stands. Likewise, sites 5 and 7 are equal in quality (SI=80) and had similar oak components in the previous stands on these sites, but the oak components in the new stands are quite different on these sites.

Table 3.--Species composition of regeneration after clearcutting on nine sites in the Southern Appalachians[1]

SITE	Y-P	NRO	OTHER OAKS	ASH-CHERRY CUC-BASS-SM	BIR	HIC	RM	DW-SW	OTHER
			--Percent of total number of stems--						
1	46	3	1	1	19	1	15	8	6
2	23	3	16	1	12	2	18	16	9
3	35	0	14	0	10	5	21	8	7
4	26	0	11	0	2	0	17	21	23[2]
5	41	0	8	5	0	1	18	8	19[3]
6	16	2	4	1	0	0	14	6	57[3]
7	14	12	13	18	2	2	10	2	27[3]
8	30	1	19	0	8	0	20	12	10
9	19	1	32	0	4	1	15	16	12

[1] Black locust excluded.
[2] Primarily pines.
[3] Primarily silverbell.

Yellow-poplar was a relatively minor component of the previous stands on sites 8 and 9, but it is a significant component of the new stands on these sites. In contrast, yellow-poplar comprised more that one-third of the volume and oaks more than one-half of the volume of the previous stand on site 6. Yellow-poplar and the oaks are greatly reduced in importance in the new stand on site 6.

Some consistent patterns are apparent when one compares the composition of the new stands with the composition of the old stands. Oaks, particularly northern red oak, are less important in the new stands than they were in the previous stands. Red maple has increased in every case. Hickory, with a couple of exceptions, was about equally represented in the new and old stands. Where silverbell was present in the old stand, it increased dramatically in the new stands.

Stocking of Desirable Species

For timber production, yellow-poplar, oaks, hickories, ash, black cherry, basswood, cucumbertree, sugar maple, birch, and pines are the most desirable species in the area. On all but one site (6), strongly competitive stems of these species outnumber those of less desirable species (table 4). However, spatial distribution (stocking) of desirable stems will be the key to the future quality and volume of these stands. On the average, more than 20 percent of the 0.01-acre plots did not have at least one desirable stem among the most dominant 5 stems per plot (table 5). Given the longevity

Table 4.--Percent of stems of desirable and less desirable timber species regenerating after clearcutting on nine sites in the Southern Appalachians

Site	Desirables	Less desirable
	--Percent of total stems--	
1	71	29
2	57	43
3	64	36
4	57	43
5	55	45
6	23	77
7	61	39
8	58	42
9	57	43

Table 5.--Percent of plots on each of nine Southern Appalachian sites stocked with at least one dominant stem of a desirable timber species after clearcutting

Site	Stocking
	--Percent--
1	71
2	84
3	78
4	80
5	78
6	47
7	85
8	74
9	83

of the less desirable species and the lack of shade tolerance of all but one of the desirable species, I would argue that 50 years from now, these 0.01-acre plots will still not be occupied by a desirable species. In other words, clearcutting with post-harvest felling of residuals has created stands less than fully stocked with desirable species, with a consequent loss of volume yield amounting to several thousands of board feet.

AN ASSESSMENT OF CLEARCUTTING

Clearcutting to regenerate Southern Appalachian hardwoods has been generally successful, particularly in comparison with the uncertain or unfavorable results obtained with the past applications of single-tree selection. Reasonably well-stocked hardwood stands have been created, and the judicious application of herbicides promises even better stocking in future harvest cuts (Loftis 1985, Zedaker 1988). However, the variability in the relative proportions of desirable species that regenerate after clearcutting must be addressed. We have reached a stage in the evolution of hardwood silviculture in which we need to ensure that our regeneration practices are meeting our regeneration goals.

THE NEED FOR REGENERATION MODELS

If one has a goal of creating a new stand with a particular mix of desirable species, the need for predictive regeneration models that can be applied prior to implementing regeneration practices becomes obvious. If such a model predicts that the regeneration goal cannot be met by clearcutting, then some alternative regeneration method must be applied, or the goal must be changed.

Some regeneration models have already been developed. For example, I have developed a model that predicts, prior to harvest, the number of dominant and codominant northern red oak stems to be expected in the next stand from on an existing population of advance red oak reproduction (Loftis 1988). This model is based on the relationship between the probability of a red oak stem becoming dominant after harvest and its preharvest basal diameter and the quality of the site on which it is growing. Competition is considered implicitly as a function of site quality. That is, for a given size of advance red oak stem, the dominance probability decreases with increasing site quality (and competition). The model requires as input an estimate of site quality and an estimate of the size distribution of advance red oak reproduction. These estimates must be obtained from sampling in the stand prior to a regeneration cut.

I believe a model for predicting species composition, as opposed to the amount of a single species, must explicitly account for interspecific competition (or other interference mechanisms). For example, consider my subjective ranking of relative post-harvest performance of different sources of regeneration--stump sprouts (SP), large (L), medium (M) and small (S) advance reproduction, and new seedlings (SE) established after harvest:

1. yellow-poplar SP; black cherry SP
2. red maple SP; silverbell SP; cucumber SP; ash SP; basswood SP; yellow-poplar L; black cherry L; birch L
3. basswood L; yellow-poplar M; black cherry M; birch M; silverbell L
4. oak[3] SP; oak L; ash L; red maple L; cucumber L; hickory SP; dogwood SP; sourwood SP; yellow-poplar S; birch S; black cherry S
5. yellow-poplar SE; black cherry SE; birch SE; oak M; basswood M; ash M; red maple M; silverbell M; cucumber M; white oak L; hickory L; dogwood L; sourwood M
6. hickory M; white oak M; sourwood M
7. oak S; ash S; basswood S; silverbell S; red maple S; dogwood M
8. white oak S; hickory S; dogwood S; sourwood S.

Sources on the same numbered line are approximately equal in post-harvest performance. Application of this ranking to a sample from the stand being considered for regeneration using, say, 0.01-acre plots on which all sources of regeneration are enumerated would allow prediction of species composition on each 0.01-acre plot. Combining the results from all plots would yield a prediction of stand composition. Note also that the effects on species composition of using herbicides to eliminate sprout competition of less desirable species can be compared with the species composition to be expected using post-harvest felling.

This conceptually simple approach to regeneration modeling may be less than satisfying to more sophisticated modelers. I would defend this approach with some observations about regeneration modeling as an important special case of succession modeling. In silviculture, the type and timing of major disturbances are controlled. Many of the uncertainties associated with disturbance regime in more general succession models need not be part of a silvicultural regeneration model. The silviculturist must prescribe for regeneration in specific stands, rather than in oak stands or cove hardwood stands in general. Given the importance of advance growth and the observed relationship between size of advance growth and post-harvest performance, the best estimate of the population of advance growth and its size distribution is provided by measurement (sampling) rather than by a stochastically determined set of values.

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[3] Oaks other than white oak--red, black, scarlet, and chestnut oaks.

Although this modeling framework may appear to be highly deterministic, stochastic elements can be and should be introduced where appropriate. For example, for species like yellow-poplar, which can regenerate from new seedlings established after a harvest cut, the probability that a plot will be stocked with new seedlings must be estimated. Furthermore, although I have provided a subjective ranking of post-harvest performance, the ranking should be based on quantitative relationships established from field data. For example, for advance-growth-dependent species, regression models of post-harvest growth as a function of preharvest attributes can be developed. For advance growth sampled on a 0.01-acre plot, the expected values from the regression models can be used to predict a unique output for species composition, or the variance associated with expected values from the regression models can be used to provide a range of possible outputs.

THE NEED FOR ALTERNATIVE REGENERATION METHODS

When regeneration models are developed, the silviculturist will be able to compare predicted species composition with regeneration goals. If predicted results do not meet regeneration goals, alternative regeneration methods must be considered. The ranking of post-harvest performance above provides a useful way to examine the effect on species composition of alternative regeneration methods. For example, I recently devised a shelterwood method that ensures maintenance of a red oak component in regenerated stands (Loftis 1988). The method involves a basal area reduction from below using herbicides, leaving the main canopy largely intact, with no large canopy gaps. The overwood is removed about 10 years after this initial treatment. The effect of this treatment is to eliminate the sprouting potential of tolerant subcanopy and lower canopy species (e.g., dogwood, red maple, silverbell), while increasing the size of red oak advance reproduction. The responses of other advance-growth-dependent species to this kind of regeneration treatment must be studied.

CONCLUSIONS

In general, clearcutting, with chainsaw felling of residual trees, has created new stands reasonably well-stocked with desirable species. However, sprouts from less desirable species frequently occupy considerable growing space, reducing stocking of desirable species. As a result, yield at rotation will be well below that potentially attainable. This problem can be overcome by using herbicides prior to, at the time of, or soon after harvest.

Even among sites of similar quality and mature-stand composition, the relative proportions of desirable species in regeneration after clearcutting can be extremely variable. This variability results from the variability in the sources of regeneration present at the time of harvest. Models are needed that can predict species composition of stands to be regenerated. Further, alternative regeneration methods are needed that can be used when the predicted results of clearcutting do not meet regeneration goals.

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RESPONSE OF IMMATURE OAKS TO PRESCRIBED FIRE IN THE NORTH CAROLINA PIEDMONT[1]

Paul Maslen[2]

Abstract.--A piedmont hardwood stand of high site quality was burned to assess oak response to prescribed fire. On sites of this quality yellow-poplar is the main competitor with oak. 7 years after the fire the amount of larger oak regeneration has increased significantly and the relative density of oak saplings and poles has more than doubled. Yellow-poplar saplings were more susceptible to topkill than oaks. Damage to stems which escaped topkill was extensive. Grapevines, abundant in the canopy prior to burning, were controlled by the fire. Repeated fires of a lower intensity are proposed, to compound the advantage of oak while restricting degrade. Such regimes, at the turn of the century, appear to have been responsible for present oak abundance on high quality sites.

INTRODUCTION

> The Salvages are accustomed, to set fire of the country in all places where they come; and to burne it twize a yeare, vixe at the Springe, and the Fall of the leafe. The reason that mooves them to doe so, is because it would otherwise be all a coppice wood, and the people would not be able in any wise to passe through the Country out of a beaten path... for this custome hath bin continued from the beginninge... For when the fire is once kindled, it dilates and spreads it selfe as well against, as with the winde; burning continually night and day, untill a shower of raine falls to quenche it. And this custome of firing the Country is the meanes to make it passable, and by the meanes the trees growe here, and there as in our parks.
>
> (Morton 1632 in Day 1953)

> The early settlers in this region [the South Carolina piedmont] were stock raisers and kept up the Indian practice of burning off the woods during the winter. The destruction of the undergrowth by this means favored the growth of grasses, and numerous herds of almost wild cattle and horses found abundant pasturage... The uplands were covered, as they still are, with a large growth of yellow pine, and a deer might have been seen in the vistas, made by their smooth stems, a distance of half a mile; where now, since the discontinuance of the spring and autumn fires, it could not be seen fifteen paces, because of the thick growth of oak and hickory that has taken the land.
>
> (Hammond 1880)

Intentional burning of the woods and its general curtailment in this century have had a major effect on the composition of the eastern hardwood forest of today. In particular the great oak woods of the better sites appear to be anomalies resulting in some way from fire. Current policy is to prevent such forests from burning. One purpose of this policy is to protect the value of growing timber from fire-caused degrade and mortality. But when these protected oak forests are harvested they do not normally regenerate themselves. It has been suggested that burning be revived as an inexpensive way to increase the proportion of oaks in future stands. (McGee 1979)

In 1980 a study was established on the Duke University Forest to investigate the relationship of fire and oak. The objectives were to determine: 1) the effect of fire on oak seedling establishment, 2) its effect on growth and survival of established reproduction and immature timber, and 3) the nature of fire damage to the boles of larger trees.[3] This paper addresses the second objective. The study reported here was intended to collect detailed data on spring head fires in order to begin evaluation of the efficacy of prescribed burns in improving hardwood stands. While the primary objective was to evaluate the effect of the burn on the oak population, of equal consequence is the relative effect on other species, notably yellow-poplar. The initial scope of this study did not permit examination of alternative burning regimes but it was hoped that it would shed some light on fire effects and suggest other treatments. Here reported are results from permanent plots and tagged stems on 3 adjacent sites burned in 1981, and resurveyed in 1981 and 1987.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] Maslen, Paul. 1981. The influence of prescribed burning on oak germination and survival. Unpublished masters thesis on file at the School of Forestry and Environmental Studies, Duke University, Durham, NC.

METHODS

The study area is near a bluff overlooking New Hope Creek in the Korstian Division of the Duke Forest. The soil is Appling sandy loam derived from acid crystalline bedrock. The 3 study sites, with a combined area of 6.5 acres, are located in a stand which received a seed-tree harvest in 1946. It is now a mixture of large residual white oaks and yellow-poplar, and poletimber. In 1980 basal area for the 3 sites averaged 111 square feet. Site index for red oak was 75-80 feet. The prominence of white oak distinguishes piedmont sites such as this from their counterparts in the southern Appalachians; the abundance of yellow-poplar distinguishes this site from those in Missouri where much oak research has been done.

Each of the 3 study sites was bissected by a disked fire line to create an area to be burned and one to serve as an unburned control. These treatments were assigned randomly. In the fall of 1980 permanent plot centers were installed on half-chain grids. From each plot center individual stems were tagged as follows: nearest oak and nearest non-oak between 1 and 5 feet tall; nearest oak and nearest non-oak greater than 5 feet tall and less than 12 inches dbh. Only arborescent species and grapevines were selected for tagging. At each plot center stems were counted on nested circular plots of 0.001 acres for those less than 2 feet in height, and 0.004 acres for those greater than 2 feet tall. On these plots stems were tallied by species in the following categories: < 2 feet tall, 2 - 5 feet tall, and 5 - 12 feet tall, and above 12 feet in height only dbh was measured. In 1987 on the burned sites the basal condition of those stems which were not topkilled was also evaluated.

Both total stems and rootstocks were counted. In this report "stems/acre" will refer to rootstocks per acre, tallied according to the largest stem in cases where there was more than one stem from the same rootstock. "Mortality" and "Survival" will refer to rootstocks rather than aboveground stems.

On March 27, 1981, the treatment halves of each site were burned with strip head fires. Fuel weight was 3.0 tons per acre, windspeed 15 mph, and the relative humidity was 30%. Flame height was 3 to 10 feet and the litter was mostly consumed. The fires were quite hot, and straight head fires would have been impossible to stop with the breaks we had.

RESULTS

Pre-burn inventory showed a substantially greater amount of understory stems on the control plots. There were about 40% more small viburnum, red maple, and eastern hophornbeam, on the control sites than on the treatment. Relative density of oaks <12 feet tall averaged 0.16 on treatment sites and 0.18 on the controls. Relative density of oaks >12 feet tall was 0.11 on both treatments and controls. White oak was the dominant oak on all sites, especially among smaller stems. 94% of oaks less than 2 feet tall were white oaks. Of larger oak advance reproduction, 58% were white oaks.

The most important data of this study are summarized next, and are contained in Tables 1 - 9. Results from the 3 different treatment and control sites have been combined. These results focus on the changes in arborescent species from the pre-burn (1980) to the most recent (1987) inventory unless otherwise noted. Plot data is presented first and then results from the tagged stems are introduced to help explain population changes.

For small advance reproduction (Table 1), on the burned site most species increased in number over the 7 year period; on the unburned sites oaks showed a similar increase while non-oak stems/ acre declined slightly. The effect of the burn was masked by large variations associated with fluctuations in seed crops of various species, including oaks. Yellow-poplar increased dramatically to 112,000 stems per acre in the first year following the fire, but by 1987 most of these seedlings had died. In 1987 the single most abundant species of small reproduction was eastern redbud (13,388 stems per acre), most of which were very small seedlings which had germinated through the years following the fire.

Data for larger regeneration was clearer. (Table 2) On the burned plots there was a general increase for all species, particularly for oaks.[4] Examination of the data for other size classes shows that at least 75% of the increase in larger oak reproduction was due to ingrowth of smaller stems. Non-oaks on the unburned sites also increased, while oak stems/acre on the unburned sites remained virtually the same.

Saplings (stems taller than 12 feet but less than 2 inches dbh) declined dramatically over all species on the burned plots (Table 3). On the control plots there was also a sharp decline, escpecially for oaks and yellow-poplar, but there were still 245 non-oak saplings/acre on the control plots in 1987.

Non-arborescent woody species were numerous in the smaller size classes (Tables 1 & 2). Viburnums were the most common of these species among stems <12 feet tall. Changes in these species after

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[4] In the 5-12 foot class red maple was the only major species whose numbers were decreased by burning. Because there was no outgrowth, this suggests that red maple is not a vigorous sprouter following fire.

Table 1. SMALL ADVANCE REPRODUCTION (stems less than 2 feet tall)

	BURN			CONTROL		
SPECIES	1980 (pre-burn)		1987 (post-burn)	1980 (pre-burn)		1987 (post-burn)
			--stems per acre--			
All oaks	2840	+1.00	5684	3575	+1.10	7506
All arborescent non-oaks	14605	+1.01	29096	19216	-0.08	17662
[Yellow-poplar]	229	+11.48	2859	141	-0.41	83
Woody shrubs & vines	9062	+0.48	13377	16237	-0.08	15037

Table 2. LARGE ADVANCE REPRODUCTION (Stems 2 - 12 feet tall)

	BURN			CONTROL		
SPECIES	1980 (pre-burn)		1987 (post-burn)	1980 (pre-burn)		1987 (post-burn)
			--stems per acre--			
All oaks	130	+1.28 *	297	144	-0.06	135
All arborescent non-oaks	1530	+0.77 *	2712	1822	+0.13	2050
[Yellow-poplar]	84	+0.95	164	78	-0.04	75
Woody shrubs & vines	446	+1.61 *	1172	734	+0.39	1018

* Pre-burn and post-burn significantly different at .95 level

Table 3. SAPLINGS (Stems taller than 12 feet, less than 2 inches dbh)

	BURN			CONTROL		
SPECIES	1980 (pre-burn)		1987 (post-burn)	1980 (pre-burn)		1987 (post-burn)
			--stems per acre--			
All oaks	52	-0.92	4	69	-0.87	9
All arborescent non-oaks	475	-0.97 *	16	577	-0.58	245
[Yellow-poplar]	62	-1.00 (*)	0	48	-0.96	2
Woody shrubs & vines	83	-0.94 *	5	66	-0.27	48

* Pre-burn and post-burn significantly different at .95 level

burning were similar to the trends of other non-oaks. (Grapevines which had climbed higher than 12 feet are included under saplings in Table 3.) On the treatment sites prior to burning there were 87 grapevines per acre in the canopy or subcanopy. By 1987 all of these vines had been topkilled and none showed any likelihood of regaining the canopy.

Pole-sized (2 - 12 inches dbh) stems of all species except oaks declined in number on the burned sites (Table 4). All major species, especially oaks, increased in number on the control sites. Relative density of oaks >12 feet and <12 inches dbh averaged .11, prior to burning, on both treatment and control. In 1987 oak relative density was about the same on the control plots (.10) but had increased to .23 on the burned plots.

Survival of tagged stems (Table 5) was substantially greater for oaks than non-oaks on the burned

Table 4. POLES (Stems 2 - 12 inches dbh)*

	BURN			CONTROL		
SPECIES	1980 (pre-burn)		1987 (post-burn)	1980 (pre-burn)		1987 (post-burn)
			--stems per acre--			
All oaks	46	+0.15	53	36	+0.78	64
All arborescent non-oaks	281	-0.41	166	281	+0.40	393
[Yellow-poplar]	107	-0.20	86	136	+0.07	145

*including outgrowth since 1980

Table 5. SURVIVAL OF TAGGED STEMS (1980-1987)

	ORIGINAL SIZE CLASS						
SITE	1-2'	2-5'	5-12'	>12',< 2"	2-6"	6-12"	Stems
			--ratio of survival--				
Burned:							
Oak	0.93	0.92	0.93	0.95	0.89	1.00	176
Non-oak	0.78	0.86	0.81	0.75	0.89	1.00	215
Unburned:							
Oak	0.89	0.93	0.89	0.73	0.94	1.00	193
Non-oak	0.86	0.91	0.96	0.74	0.91	1.00	210
Stems	249	149	125	138	111	22	794

plots, particularly in the smallest size class. Generally oaks showed no mortality from burning while non-oaks show atleast a mild effect. Saplings as a class were more prone to mortality (except for oaks on the burned plots).

Topkill was not restricted to the burned plots. On the control, in the absence of disturbance, about 1/2 of the oak stems less than 12 feet tall, and about 1/3 of the non-oaks, died back over the 7 year period. (Table 6) Among stems >12 feet tall non-oaks were topkilled much more frequently on the burned plots. Oaks of this size showed little effect from the fire. The large percentage of oak stems escaping topkill and increasing in size class (Table 7) indicates that the reduction in oak saplings/acre (Table 3) was largely due to outgrowth. The reduction in non-oak saplings/acre was evidently due to topkill and mortality. Also, the percentage of small oak stems (1-2 feet tall) increasing in size class was much higher on the burns than on the controls-- further evidence that the increase in larger oak reproduction was due to ingrowth. Non-oaks of this size class had a high percentage of outgrowth on both the burned and unburned plots.

The positive growth rate of oak and non-oak stems <12 feet tall on the treatment plots expresses the vigorous sprouting which occurred after topkill by the fire (Table 8). Tagged oaks on the control plots have died back since 1982, in contrast to non-oaks.[5] The increased radial increment for non-oak stems <6 inches in dbh on the treatment plots probably reflects the greater vigor of those stems which escaped topkill. Radial growth does not appear to have been reduced by the fire.

Finally, oaks (and yellow-poplar) were found to be more resistant than other species to basal wounding (Table 9). Among stems of <12 inches dbh not topkilled by fire, oaks more often showed no visible wound, and among wounded trees, were more likely to have healed over than non-oaks over the 7-year study period.

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[5] Oak stems originally in the 5-12 foot class (most vigorous advance reproduction) have, on the average, failed to regain this size on the burned plots. In 1987 the average height was only 3.40 feet, but lower still on the controls (3.18 feet).

Table 6. ESCAPING TOPKILL, TAGGED STEMS (1980-1987)

	ORIGINAL SIZE CLASS						
SITE	1-2'	2-5'	5-12'	>12',< 2"	2-6"	6-12"	Stems
			--ratio escaping topkill--				
Burned:							
Oak	0	0	0	0.45	0.73	1.00	176
Non-oak	0	0	0	0.02	0.50	1.00	215
Unburned:							
Oak	0.55	0.50	0.39	0.48	0.88	1.00	193
Non-oak	0.63	0.72	0.64	0.63	0.91	1.00	210
Stems	249	149	125	138	111	22	794

Table 7. INCREASING IN SIZE CLASS (1980-1987)

	ORIGINAL SIZE CLASS						
SITE	1-2'	2-5'	5-12'	>12',< 2"	2-6"	6-12"	Stems
			--ratio increasing--				
Burned:							
Oak	0.39	0.08	0	0.36	0.41	0.14	176
Non-oak	0.47	0.20	0	0.02	0.11	0.25	215
Unburned:							
Oak	0.17	0.07	0.06	0.33	0.29	0	193
Non-oak	0.36	0.28	0.16	0.29	0.32	0.25	210
Stems	249	149	125	138	111	22	794

Table 8. GROWTH INCREMENT (Average for tagged stems, 6 growing seasons through 1987)

	ORIGINAL SIZE CLASS						
SITE	1-2'	2-5'	5-12'	>12',< 2"	2-6"	6-12"	Stems
	--Height increment (feet)*--			--Radial increment (inches)**--			
Burned:							
Oak	+1.58	+2.09	+2.41	0.46	0.59	1.00	146
Non-oak	+1.98	+2.31	+2.90	0.62	0.61	0.66	135
Unburned:							
Oak	n.c.	-0.60	-2.58	0.34	0.60	1.14	160
Non-oak	+0.13	+1.42	-0.17	0.24	0.32	0.32	181
Stems	217	134	114	49	86	22	622

* Surviving stems only

** Stems escaping topkill only

Table 9. BASAL WOUNDING OF BURNED STEMS (Less than 12 inches dbh, not topkilled)

CONDITION (1987)	SPECIES All Oaks	Yellow-poplar	Other Non-oaks	Stems/acre
Old cambium still exposed	0.30	0.32	0.56	99
Healed over wound	0.26	0.26	0.19	56
No visible wound	0.43	0.41	0.25	85
Stems/acre	57	86	97	240

DISCUSSION

There are 4 periods in the growth of an oak tree during which fire might be used to enhance oak regeneration-- seed germination, advanced reproduction, the period immediately after harvest, and the sapling and pole stage.

We hypothesized that a fire which burned to mineral soil, in a mature oak stand, would provide an ideal seed bed for acorns. Subsequent leaf-fall would protect the acorns from dessication and predation. These are the conditions that have been shown to be optimum for acorn germination and early survival (Korstian 1927). I planned to test this hypothesis as part of this study but the acorn crop was poor. In 1985, after a good seed year, new white oak seedlings appeared to be about equally abundant on the treatment and control sites.

Oaks are regenerated from advance reproduction and stump sprouts. It has been demonstrated that successful regeneration of oak depends upon the size of advance reproduction rather than sheer numbers (Sander 1971). New seedlings and stems less than 1 foot tall (at harvest) have virtually no chance to contribute dominant or codominant stems to the next stand. Fire could favor oak representation by creating conditions for the enlargement of advance reproduction. This could occur if there were a great enough difference in the survival of oak regeneration versus small stems of other species.

In this study, comparison of the burned and unburned sites shows that fire increased the number of stems in the larger categories of advance reproduction for oaks as well as non-oaks. This increase for oak was due to ingrowth, i.e. small advance reproduction becoming larger as a result of the fire. On the other hand, oak stems on the unburned sites seem to be in a steady cycle in which a large number of seedlings germinate in sporadic good seed years, most of these seedlings die, some persist and undergo periodic topkill and eventual mortality-- unless the stand is disturbed.

These data are evidence that a single fire can increase the size of oak advance reproduction. Whether one fire has significantly improved the outlook for oak in the next stand is another question. The only available method for predicting the significance of changes wrought by the fire is the guidelines of Sander et al (1984). If their method is applied to the 1980 data neither the treatment or control is predicted to regenerate their goal of 221 oak stems/acre. In 1987 both treatment (+74) and control (+62) are predicted to exceed this level. If advance reproduction less than 2 feet tall is excluded, both treatment (102 to 104) and control (119 to 83) fall far short of regenerating oak, before and after the burn. On good sites in the Appalachians the probability of oak stems less than 2 feet tall succeeding after harvest may be nil.[6] Also, it seems likely that fire effects would confound Sander's guidelines.

The data of Tables 2,3, and 4, for the unburned sites, suggest a long-term trend toward reduced numbers of larger oak reproduction, increased dominance of the understory by non-oaks, and a declining capacity to regenerate oak. These developments were somewhat retarded, if not overhauled, by the fire.

After a mature overstory is clearcut a multitude of regeneration normally develops-- Oaks are usually poorly represented on good sites. If oaks sprouted more dependably and more vigorously after burning than non-oaks, a fire at this stage (which would topkill all stems) might improve the position of oak in the developing stand. The present study made no test of this hypothesis. Other work has thus far failed to validate it. (Huntley and McGee 1981)

The final period in which oak representation might be enhanced is during the sapling and poletimber stage. During this period the faster growing species (e.g. yellow-poplar) close the canopy and ensure that oaks will not be abundant in the mature stand. The survival of advance reproduction, when burned, depends upon its ability to sprout following topkill, but the survival of saplings and poles in a young stand depends upon the ability to resist topkill. In this respect oaks were markedly more resistant to fire than all other species. Among tagged oak saplings fire increased neither topkill or mortality (Tables 5 & 6). Of non-oak saplings less than 2 inches in dbh, only 1 tagged stem in 48 escaped topkill. A sapling-sized stand with an adequate amount of oak, burned with a fire similar to these, could be converted to an oak stand. This is exactly the result reported from a wildfire in West Virginia. (Carvell and Maxey 1969) Results from the permanent plots are also suggestive of oak's superior resistance to fire: on the burned sites 58% of oak stems greater than 12 feet tall (and less than 12 inches dbh), but only 25% of non-oak stems, escaped topkill. Comparison with the control plots, where oak topkill was only slightly lower, indicates that oak stems taller than 12 feet are large enough to escape topkill from a fire such as this, but non-oak stems do not become similarly resistant until they reach 2 inches or more in dbh. In between those sizes oaks thrive and non-oaks die back.

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[6] David Loftis, personal communication.

YELLOW-POPLAR

Yellow-poplar, in particular, changes from a thin-barked tree susceptible to topkill by fire to a thick-barked (fire resistant) tree at about 2 inches of dbh.[7] This change is more dramatic for yellow-poplar than for any other major piedmont hardwood species. In a report on basal fire wounds to larger trees yellow-poplar was found to be the most fire resistant of all southern Appalachian hardwoods. (Nelson et al 1933) In this study, among stems larger than 2 inches dbh, yellow-poplar was almost as resistant to topkill as the oaks, so a fire such as this in a pole stand would probably only eliminate other species, leaving plenty of yellow-poplar to compete with oak. Even if the target level of Sander's guidelines (Sander et al 1984)-- C-level stocking when mean stand dbh is 3 inches-- could be achieved, yellow-poplar stems would probably have to be deadened or cut to assure that oaks remain free-to-grow. Elimination of yellow-poplar from sites where it naturally thrives should, of course, not be encouraged. Besides its considerable timber value it is immune to defoliation by the gypsy moth (which is a greater threat to our oak stands than the lack of adequate regeneration). Gottschalk (1986) has suggested limiting oak stocking to 15 or 20 % to protect against defoliation of oak and other species. On a good site this level is also a more practical goal than full oak stocking.

Stocking guidelines for oak reproduction have been based upon the numbers of oak stems of certain sizes, with only indirect consideration given to competition from reproduction of other species. The role of other species could be expected to vary according to the region. From Pennsylvania to Georgia yellow-poplar is the main competitor with oaks on good sites. Yellow-poplar produces more seed more dependably than oak and the seed remains viable for several years. Because yellow-poplar (unlike red maple or sweet birch) maintains a vigorous rate of growth through long periods of stand development, the number of oaks required for adequate stocking on these sites probably varies according to the number of yellow-poplar. Yellow-poplar regeneration normally develops from seed stored in the organic layer of soil at the time of harvest. It does not germinate unless there is a disturbance to the soil or overstory. (Carvell and Korstian 1955) Fire seems to destroy the most recent crop of yellow-poplar seed and create conditions for the germination of a large amount of the stored seed. If yellow-poplar seed could be burned, and exhausted by subsequent germination and mortality (as occurred in this study), competition with oak regeneration following harvest would be greatly reduced.

GRAPEVINES

Another important competitor in young hardwood stands is grapevines. Grapevines can be a particularly serious problem following clearcutting or other even-aged management. (Smith 1984) In this study the 87 grapevines per acre which were present in the canopy prior to burning (on the treatment sites) were all topkilled by the fires. Grape seedlings and sprouts are difficult to count because of layering, but there were roughly twice as many small grape stems/acre on the burned sites in 1987 (3833) as in 1980 (1791). Fire may increase the grapevine problem if used to foster advance reproduction, but it could be a good tool for eliminating them from the canopy of a young stand.

FIRE WOUNDS

If fire were used to foster advance reproduction, damage to the overstory might still exceed any advantage gained in the species composition of the next stand. Fire damage to mature trees would probably be insignificant if the trees were harvested promptly. But if several years were to pass between a fire of the intensity of those in this study, and the final harvest, degrade to the butt logs would probably be unacceptable.

As promising as prescribed fire appears to be for timber stand improvement, fires of the intensity of these would be undesirable because of basal wounding of the young stems which escape topkill. 30% of the oak stems suffered wounds which have left the dead cambial tissue exposed after 7 years. This applies to other species as well as oak. Although red maple saplings and poles have almost been eliminated, for example, the few stems that remain have grotesque fire wounds. Carvell and Maxey (1969) noted basal scars or rot on 41.5% of the dominant trees after a fire in a pole stand. In a study of bottomland hardwoods, Kaufert (1933) found that "fire scars on young trees heal over much more slowly than do scars on mature trees of the same species... [On young trees] the average fire scar remained unhealed 15-20 years after injury. Completely healed fire scars were exceedingly rare on the young trees examined." If healed over, fire damage to saplings should be of no consequence to the eventual value of the mature tree. Fire wounds which fail to heal over in 20 years would, at the least, seriously degrade butt log value, and at worst result in a stand of culls. Perhaps repeated fires of a lower intensity than these would result in an accumulating advantage to oak stems without the damage these fires caused to surviving stems.

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[7] Maslen, Paul. 1981. The influence of prescribed burning on germination and survival of oaks. Unpublished masters thesis on file at the School of Forestry and Environmental Studies, Duke University, Durham, NC.

Basal wounding does not appear to have caused any reduction in diameter growth. Another report on fire in eastern hardwoods found that even severe basal wounding did not retard diameter growth of white oaks and yellow-poplars. (Jemison 1943)

BURNING PERMITS

Above average moisture is a determinant of good sites. Although these sites frequently become dry enough to burn, this may not occur until drier sites nearby have reached the point of extreme fire hazard, causing local officials to ban burning. If fertile hardwood sites were to be burned operationally the issuance of burning permits would have to be adjusted to account for moisture variations on different sites.

CONCLUSIONS

Oak stands on good sites appear to have developed from the cessation of annual burning, not from a single fire or by continued burning. The most dramatic result of a single fire was the ability of oak saplings and poles to escape topkill. But degrade from basal wounding of surviving stems may exceed any benefit available from burning. Although the size of oak reproduction was significantly increased by the fire, prediction of the consequences of such an increase would be improved by the development of oak stocking guidelines tailored to the southeast. In particular, an evaluation of yellow-poplar seed source should be incorporated into such criteria. Where yellow-poplar is the main competitor with oak, it is not practical or desirable to eliminate it from the next stand.

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DEVELOPMENT OF ADVANCED REPRODUCTION FOLLOWING PRELIMINARY CUTTINGS OF A SHELTERWOOD HARVEST[1]

Eric J. Schmeckpeper, Larry M. Doyle,
and Elizabeth M. Wellbaum[2]

Abstract.--A 43-acre upland oak-hickory stand was used to demonstrate the shelterwood harvest system as practiced on TVA's Land Between The Lakes (LBL) national recreation area. Treatments were: seed cut harvest in the winter of 1978 removing 27 percent of the initial basal area of 94 square feet per acre with chemical injection of all unmarked stems 1 to 11 inches DBH (an additional 10 square feet per acre); partial removal harvest in October 1985 removing approximately 25 square feet basal area per acre. Twenty permanent regeneration plots were established in 1980 for tracking annual changes in small (height $\leq$4.5 ft) and large (height >4.5 ft) advanced reproduction. Two years after the second harvest the stand is fully stocked with desirable large advanced reproduction, and 70 percent of plots are stocked with oak or hickory. In addition, 95 percent of the plots are stocked with small oak or hickory reproduction. The final removal harvest is scheduled for 1992.

INTRODUCTION

TVA's Land Between The Lakes (LBL) national demonstration and recreation area in western Kentucky and Tennessee occupies a 170,000-acre peninsula between the Tennessee and Cumberland Rivers. The primary objective of the resource management program is to "restore and/or improve the natural resources of LBL [in order] to provide a wide variety of opportunities for outdoor recreation, environmental education, and interpretation for a rapidly urbanizing society" (TVA 1985). The LBL forestry program integrates a seven-year cycle of timber harvests and other forest management practices with wildlife habitat needs to create a forest size class distribution compatible with recreation, environmental education, and aesthetics.

The shelterwood system is practiced on most of LBL in order to regenerate natural, even-aged oak-hickory stands. This method is intended to establish an acceptable level of oak regeneration before the final removal harvest. Thinnings and improvement cuts which leave oak in a dominant crown position contribute to the shelterwood method. Ideally, oak crop trees develop large crowns and produce abundant acorns for stand regeneration. These harvests also create the necessary light and soil conditions on the forest floor for the acorns to germinate and grow.

The shelterwood method begins with a preparatory cut to expand the crowns of the crop trees for seed production, removing overtopped and intermediate trees. On LBL, this is generally considered an improvement or salvage cut (Table 1). It may also be necessary to cut or deaden nonmerchantable saplings and poles to reduce understory competition. A seed cut is conducted next to establish reproduction after the least desirable stems of the dominant and codominant classes are removed. Finally, one or more removal cuts remove the last of the overstory and release the established regeneration. Most shelterwood harvests on LBL are either two-staged harvests with the preparatory and seed harvests combined, followed by a single removal harvest, or multi-staged with the preparatory and seed cuts followed by one or more removal harvests.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Forester, Land Stewardship Supervisor, Forester, respectively, Tennessee Valley Authority, Land Between The Lakes, Golden Pond, Kentucky 42231.

METHODOLOGY AND STUDY AREA

The study area is an upland oak-hickory stand on a convoluted east-facing slope. The predominant oak species are white oak (Quercus alba), scarlet oak (Q. coccinea), southern red oak (Q. falcata), and chestnut oak (Q. prinus) along the ridges. Soils on this site are deep and well-drained soils formed from gravelly to very gravelly coastal plain material on the uplands. Site indices for upland oak range from 50 to 69, depending on soil type and aspect (Humphrey 1981). These are typical LBL soils.

We have no records for harvests occurring in this stand before TVA acquisition in 1964. However, it is unlikely that the stand was cut between 1938 and 1964 while under the management of the U.S. Department of the Interior Kentucky Woodlands National Wildlife Refuge. Some evidence of past fires was observed in TVA's first inventory, although the stand has not been burned recently.

Table 1.--Cutting practices used at LBL.

Practice	Description
Noncommercial:	
T.S.I.	Cutting or chemically treating nonmerchantable stems.
Commercial:	
Improvement/ Salvage Cut	First cut of management: Trees removed are inferior compared to leave trees. This harvest is often the same as crown or removal thinning depending on individual stand conditions.
Low Thinning	Preparatory cut of shelterwood system: removes overtopped and intermediate trees from the understory.
Crown Thinning	Removal of least desirable stems in the dominant and codominant classes. The seed cut of the shelterwood system.
Removal Thinning	These cuttings may extend over a period of 21 years. The final removal cut removes the last of the overstory and releases oak regeneration.
Delayed Release	Cutting the sawtimber overstory from a 2-storied sapling/pole stand.
Patch Clearcut	Stands are clearcut in 5- to 10-acre blocks over two or three harvest cylces.

The initial inventory in 1977 indicated 84 square feet of basal area per acre with full shade (Table 2). Very little advanced regeneration was noted. The stand was marked in the fall of 1977 to cut about 21 square feet of basal area per acre in sawtimber and 9 square feet of basal area per acre in pulpwood. Following marking, noncommercial stems in the 1- to 11-inch DBH range (approximately 10 square feet of basal area) were injected with 2,4-D. A combination preparatory and seed cut was conducted in the winter of 1978 (Figure 1).

Table 2.--Stand history.

Year	Activity	Volume per Acre Board Feet	Basal Area per Acre Square Feet
1977	Inventory	5,737	84
1977	T.S.I.		-10
1978	Harvest	-2,138	-31
		3,599	43
1984	Inventory	4,750	54
1984	Harvest	-1,310	-18
		3,440	36
1988	Inventory	(not measured)	32

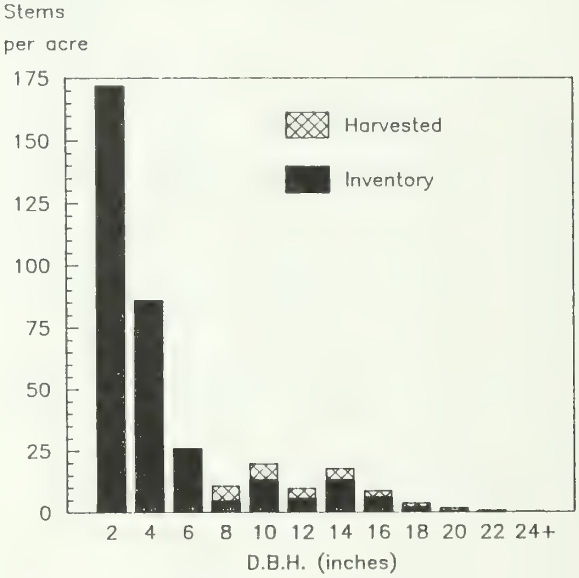

Figure 1.--Diameter distribution before and following initial harvest in 1978.

In 1980, twenty 1/735-acre permanent regeneration plots were established and remeasured annually (except in 1986), using "A guide for evaluating the adequacy of oak advanced regeneration" (Sander, Johnson, and Watt 1976) as a guide for our methods. Plots are considered stocked if they contain at least one stem for a given species or size. Species were tallied as red oak group, white oak group, chestnut oak, hickory (Carya spp.), or other.

A removal harvest conducted in 1985 removed another 18 square feet of basal area in sawtimber and pulpwood, further opening the canopy (Figure 2).

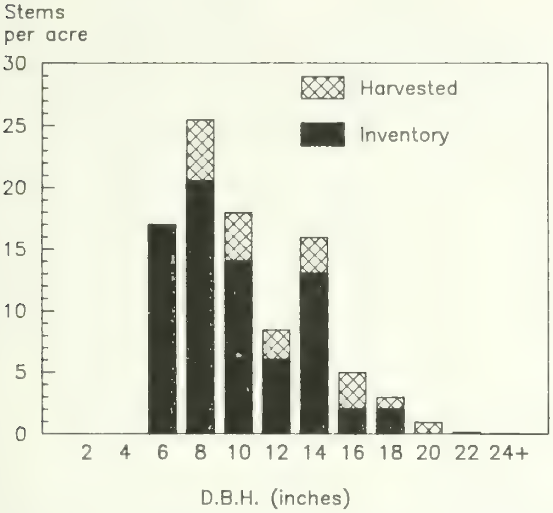

Figure 2.--Diameter distribution before and following the 1985 partial removal harvest.

RESULTS AND DISCUSSION

Regeneration was prolific after the 1978 harvest for oaks, hickories, and other species (Table 3). Other species included sugar maple (Acer saccharum), red maple (A. rubrum), dogwood (Cornus spp.), elm (Ulmus spp.), sassafras (Sassafras albidum), and blackgum (Nyssa sylvatica). Many of these species are considered desirable for wildlife food production, even though they are regarded less favorably for timber production. On this site, some of these other species must be expected to compose a portion of the developing stand.

Table 3.--Regeneration by height class for 1980 and 1988.

	Stems per Acre			
	1980		1988	
Species	<4.5'	≥4.5'	<4.5'	≥4.5'
White oak group	3,197	37	1,948	147
Red oak group	2,352	37	1,470	441
Chestnut oak	2,793	184	1,029	515
Hickory spp.	1,286	0	1,103	294
Oaks + Hickories	9,628	258	5,550	1,397
Others	7,056	37	4,594	1,507
Total	16,684	295	10,144	2,904

In 1980 there were nearly 10,000 oak and hickory stems per acre. However, early abundance of small oak regeneration is not a good indicator of whether oaks will be a major component in the new stand (Sander and others 1976). Only 15 percent of the plots were stocked with oak-hickory regeneration taller than 4.5 feet, large enough to compete for light, space, water, etc. Distribution of large regeneration, rather than number of stems, determines the timing of the removal cuts. According to our guidelines, a stand is adequately stocked when desirable stems occur over 59 percent of the plots.

Since 1980, stocking of large oak-hickory regeneration has increased (Figure 3) and is currently at 70 percent for the entire stand. Stocking of small regeneration has remained relatively constant.

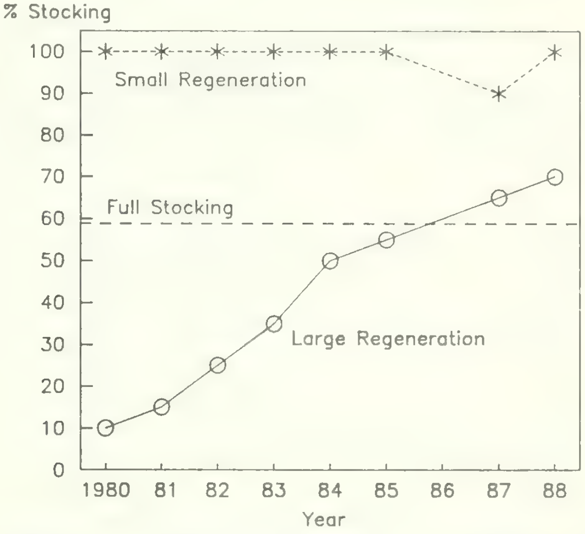

Figure 3.--Percent stocking for oaks and hickory between 1980 and 1988.

According to our guidelines, the stand is now fully stocked with one large oak or hickory stem occurring over 70 percent of the plots. This stand will be harvested again in 1992, at which time half of the area will receive a final removal cut. Residual stems on the other portion will be retained to evaluate long-term survival of regeneration beneath the light overstory. We are interested in this modification of the removal cut for wildlife management (dens, perch trees, etc.) and aesthetic reasons, provided regeneration results are successful.

CONCLUSIONS

This stand will be fully stocked with oak and hickory seedlings and sprouts after the final removal harvest. This treatment is typical of the type of harvesting system used at LBL on an operational basis. Whether a seed cut is needed depends on the amount of basal area removed in the initial cut.

The shelterwood system is of interest to us because of its potential to satisfactorily regenerate a mixed oak-hickory stand over time, with substantially less visual impact for recreation users while satisfying wildlife habitat needs. For other public or private forest managers having similar objectives and similar forest conditions, the shelterwood approach may be applicable with suitable modifications. We have observed that most of the management cuts suitable for use in Land Between The Lakes fall into some stage of a shelterwood system and that the shelterwood system is an invaluable tool for managing the upland oak-hickory forest under even-aged management.

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SPROUT DENSITY: AN INDEX OF COPPICE ESTABLISHMENT [1]

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and
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Abstract.--Unit-area crown coverage is an intuitively attractive criterion of hardwood coppice establishment, but it is expensive to estimate and judgement or measurement error is inherent in data collection. Crown coverage generally appeared to be related to number of sprouts per unit area in Upper Piedmont hardwood mixtures and Coastal Plain oaks. Number of sprouts per unit area was, therefore, examined as a substitute for crown coverage on Upper Piedmont and Coastal Plain sites. This proved appropriate for individual Piedmont species of a given age on similar sites. However, it is not appropriate for most Piedmont species mixtures, for Coastal Plain oaks, or under varying site conditions. [3]

INTRODUCTION

Measures of coppice establishment have included sprouts per stump or clump, number of sprouts or sprouting stumps per unit area, sprout height, and areal coverage. One of the most desirable measures from a theoretical and management standpoint is unit-area crown coverage, especially for species that are intermediate to intolerant to shade. Crown coverage can be expected to reflect the predominance of a species on an area, biomass, or leaf area basis. It is useful in research (McMinn 1985, 1987), but is expensive to estimate and judgement or measurement error is inherent in data collection. Preliminary analyses of data from Upper Piedmont mixed hardwood stands collected for a previous study (McMinn and Nutter 1988) indicated a strong relationship between crown coverage and number of sprouts per unit area. In a combined analysis for all species on 12 plots representing four harvesting treatments, number of sprouts accounted for 93 percent of the variation in coverage 2 years after harvesting and 97 percent after 4 years. Data from studies to determine site-fusiform rust relations indicated similar general trends appeared to exist for Coastal Plain oaks.

If sprout counts were reliable indices of coppice establishment, data collection would be simpler, faster, and involve no inherent measurement error. However, legitimate use of such an index depends on the degree to which the relationship between crown cover and sprout density varies with species and other factors. The study reported here focused on defining conditions under which sprout density is an appropriate substitute for coppice crown cover. To that end, we examined how the relationship of crown cover to number of sprouts varied: (1) by treatment and species at 2 and 4 years after harvesting in Upper Piedmont mixtures, and (2) by soil drainage class and species in Coastal Plain oaks approximately five growing seasons after harvesting.

METHODS

Piedmont

Data for the Piedmont phase were collected in a study of whole-tree harvesting (McMinn and Nutter 1988). The study area is about 40 mi NNE of Atlanta on the Dawson Forest in the Upper Piedmont of Georgia. The area consisted of abandoned agricultural fields that had naturally seeded to

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[3] The authors gratefully acknowledge the cooperation and support of the Georgia Forestry Commission and member companies of the Integrated Forest Pest Management Cooperative.

pine and undergone high-grading prior to management by the Georgia Forestry Commission. The soils, Ultisols, are eroded phases of Fannin fine sandy loam, a Typic Hapludult, with inclusions of Tallapoosa fine sandy loam, an Ochreptic Hapludult. Table 1 displays basal area distribution by species group and broad size classes. In descending order of basal area, the species in preharvest stands included scarlet oak (Quercus coccinea Muenchh.), post oak (Q. stellata Wangenh.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.), southern red oak (Q. falcata Michx.), hickory (Carya spp.), blackjack oak (Q. marilandica Muenchh.), sourwood (Oxydendrum arboreum (L.) DC.), white oak (Q. alba L.), dogwood (Cornus florida L.), and blackgum (Nyssa sylvatica Marsh.).

Table 1.--Preharvest Upper Piedmont stand basal area by species group and size class

Species group	Size class: Sapling	Pulpwood	Sawtimber	Total
	- - - - - - Ft^2/acre - - - - - -			
Pine	7	15	3	25
Red oaks	5	8	12	25
White-post-chestnut oak	5	6	8	19
Other hard hardwoods	4	2	2	8
Soft hardwood	1	1	1	3
Shrub	1	-	-	1
Miscellaneous	6	3	1	10
All Species	29	35	27	91

Two intensities of whole-tree harvesting were imposed on the stands. The more intensive treatment removed all stems down to approximately 1 inch dbh, which included virtually all of the woody biomass. The less intensive removal included all stems down to approximately 4 inches dbh. Harvesting at the two intensities was conducted in both January and June of 1980. Harvested plots were 1-acre squares. Each season and intensity combination was replicated three times in a completely randomized design. Data collection was confined to the interior half acre of each acre plot.

After the second and fourth growing seasons, all hardwood sprout clumps that were at least breast height were measured. Number of sprouts and average crown diameter at the height of maximum crown spread were recorded for each sprout clump. Sprout coverage per acre was defined by the formula:

$$(1)\quad C = (\pi/2) \sum_{i=1}^{N} W_i^2$$

where C is coverage (ft^2/Acre), W_i is average width of the crown projection for clump i, and N is the total number of sprout clumps.

The Statistical Analysis System (SAS) analysis c covariance procedure (SAS Institute Inc. 1985) was used as a convenient mechanism for conducting a sequence of tests in which coverage was the dependent variable and number of stems was the covariate. The null hypothesis for the first test was that there is no relationship between number c sprouts and crown coverage for any harvesting treatment; that is, that the slopes are all zero. The null hypothesis for the second test was that there is no difference in the slope of the relationship among harvesting treatments. The third test was for a significant slope when the data for all harvesting treatments are combined. The analyses were run by species and year for thos species that were represented on all plots in the year of measurement. Linear regression equations relating crown cover to number of stems were then developed for general comparisons and contrasts among species and years.

Coastal Plain

Data for the Coastal Plain phase were from a study on the effects of alternate host coverage ar soil drainage class on the incidence of fusiform rust (Cronartium quercum (Berk.) Miyabe ex Shirai f. sp. fusiforme). In the Atlantic Coastal Plain water oak (Quercus nigra L.), laurel oak (Q. laurifolia Michx.) and bluejack oak (Q. incana Bartr.) are the most prevalent and important alternate hosts of fusiform rust.

Oak coppice was inventoried in 5-year-old slash (Pinus elliottii Engelm. var. elliottii) and loblolly pine (Pinus taeda L.) plantations in the Coastal Plain of Florida and Georgia. Forty-two plantations were selected in three geographic areas--eastern Florida, western Florida, and central Georgia--based on rust incidence and soil drainage classes (Schmidt et al. 1986, 1988). Fou soil drainage classes were represented in the data set: 1) well-drained, 2) moderately well-drained, 3) somewhat poorly drained, and 4) poorly drained Average depths to the water table were 60-80, 40-60, 20-40 and 0-20 inches, respectively. Preliminary analyses produced no significant differences in the average number of oak stems per acre between well-drained and moderately well-drained soils, or between somewhat poorly drained and poorly drained soils. For this study, drainag classes 1 and 2 were combined and classified as well-drained soils, while classes 3 and 4 were combined and classified as poorly drained soils.

Study plantations were systematically sampled using 0.01-acre circular plots equally spaced between and within rows. Sequential sampling, based on the frequency and distribution of oaks, was used to classify individual plantations according to oak density. The average number of plots per plantation was 41 and ranged from 12 to 51. For all oak sprouts, species, number of stems per sprout clump, and average clump crown diameter at the height of maximum crown spread were recorded. Number of clumps, total stems, and sprout clump coverage were transformed to a per-acre basis for analysis.

RESULTS

Piedmont

The test results were quite consistent across species (table 2). There was only one case (hickory at age 4) in which the slope was not significant for any treatment. Similarly, there was only one case in which there was a significant difference in slope among harvesting treatments--chestnut oak at 2 years. When the data for all treatments were combined, there was a significant relationship between number of stems and crown coverage for all species at both stages of coppice development. Therefore, there is a significant relationship between number of sprouts and crown coverage, which is not affected by harvesting treatment.

Table 2.--Results of a sequential set of analyses on the relationship of crown coverage to number of sprouts in Upper Piedmont mixed coppice stands

Species	Slope: Greater than zero for any treatment	Slope: Differences among treatments	Slope: Greater than zero, treatments combined
	2-Year Coppice		
All	** [1]	NS	**
Dogwood	**	NS	**
Sourwood	**	NS	**
Scarlet oak	**	NS	**
Southern red oak	**	NS	**
Blackjack oak	**	NS	**
Chestnut oak	**	*	**
	4-Year Coppice		
All	**	NS	**
Hickory	NS	NS	*
Dogwood	**	NS	**
Blackgum	*	NS	**
Sourwood	**	NS	**
White oak	**	NS	**
Scarlet oak	*	NS	**
Southern red oak	*	NS	**
Chestnut oak	**	NS	**
Post oak	*	NS	**
Black oak	*	NS	**

[1] ** = significant at the 0.01 alpha level,
 * = significant at the 0.05 alpha level,
NS = nonsignificant.

General contrasts and comparisons for species and years are afforded by the linear expressions best describing the relationship of crown coverage to stem number (table 3). At 2 years none of the intercepts were significantly different from zero. At 4 years, three intercepts were significantly different from zero, probably due to sampling error. Slopes were significantly different from zero for all species at both stages of development. At 2 years, slope coefficients ranged from approximately 2.05 to approximately 5.48 square feet of coverage per stem and at 4 years approximately 2.07 to 6.51. Coefficients of determination were generally high at 2 years and extremely high at 4 years.

Table 3.--Regression coefficients and coefficients of determination for crown coverage on number of stems by species and years since harvesting

Species	Intercept	Slope	R-square
	2-Year Coppice		
All	197.8	3.438** [1]	0.93
Hickory	9.0	2.184*	0.41
Dogwood	52.2	2.047**	0.88
Blackgum	9.5	2.609**	0.97
Sourwood	165.1	2.262**	0.69
White oak	36.0	2.797**	0.74
Scarlet oak	49.6	3.688**	0.92
Southern red oak	42.5	4.592**	0.78
Blackjack oak	-12.1	4.785**	0.98
Chestnut oak	8.7	4.228**	0.93
Post oak	- 5.8	5.479**	0.92
	4-Year Coppice		
All	1184.6*	3.950**	0.97
Hickory	11.1	2.072**	0.93
Dogwood	123.8*	2.585**	0.95
Blackgum	- 4.8	2.569**	0.90
Sourwood	92.3	3.211**	0.92
White oak	160.3**	3.411**	0.98
Scarlet oak	32.2	5.832**	0.91
Southern red oak	102.4	6.508**	0.83
Blackjack oak	- 3.6	4.597**	0.93
Chestnut oak	170.7	6.582**	0.98
Post oak	26.7	4.137**	0.78
Black oak	37.3	4.820**	0.85

[1] ** = significant at the 0.01 level
 * = significant at the 0.05 level.

Number of stems per clump varied by species and stage of development (table 4). At 2 years, the maximum number of stems per clump was lowest for post oak (12) and highest for chestnut oak and sourwood (36). At 4 years, post oak still had the lowest (11) and scarlet oak the highest (31). Between 2 and 4 years the maximum number of sprouts per clump dropped for every species except scarlet oak and blackjack oak.

Table 4.--Range in number of stems per sprout clump for 11 Piedmont species two and four growing seasons after harvesting

Species	Range: Two-year	Range: Four-year
	- - - - Stems/clump - - - -	
Hickory	1 - 25	1 - 13
Dogwood	2 - 26	1 - 25
Blackgum	1 - 17	1 - 12
Sourwood	2 - 36	2 - 26
White oak	2 - 16	1 - 13
Scarlet oak	1 - 28	1 - 31
S. red oak	1 - 22	1 - 14
Blackjack oak	1 - 13	1 - 14
Chestnut oak	1 - 36	1 - 22
Post oak	1 - 12	1 - 11
Black oak	-	1 - 14

Coastal Plain

After 5 years, occurrence and abundance of oaks were significantly greater on the well-drained soils than on the poorly drained soils (table 5). The difference in sprout clump coverage was particularly striking, averaging 2987 square feet per acre on the well-drained soils compared to 548 on the poorly drained soils. Water oak occurred in 81 percent of the plantations and had the most stems and sprout crown coverage per clump and per plantation (table 6). Laurel oak was intermediate in occurrence and crown coverage per acre. Bluejack oak had the smallest crown coverage per individual clump and per acre.

Crown coverage was linearly related to number of sprout stems per acre for all combinations of species and soil drainage class. Oaks on the two drainage classes were treated as two distinct populations because they differed substantially in crown area variability. Tests for homogeneity of regressions among species within drainage classes were nonsignificant, so species were combined. The prediction equation for well-drained soils (fig. 1) was:

$$CROWNCA = 309.32 + 12.35(STEMSA);\ r^2=0.51$$

where

CROWNCA = crown coverage (ft^2/acre)

STEMSA = number of sprout stems per acre.

Table 5.--Average sprouting characteristics of all oaks by soil drainage class in 5-year-old Coastal Plain stands

Soil drainage class	Plantation	Occurrence	Clumps	Stems	Coverage
	-Number-	-Percent-	Number/ -acre-		Ft^2/ -acre-
Well	20	95	132	208	2987
Poorly	22	73	48	74	548

The prediction equation for poorly drained soils was:

$$CROWNCA = 6.68(STEMSA) - 8.14;\ r^2=0.76$$

Estimates were more precise for the poorly drained sites because substantially less variation occurre under that condition.

Crown coverage was also linearly related to number of sprout clumps per acre. Again, F-tests of conditional error produced no significant differences (P=0.47) among regressions by species. For well-drained soils the regression model was:

$$CROWNCA = 222.3 + 21.84(SPCLA);\ r^2=0.55$$

where

SPCLA = number of sprout clumps per acre.

The prediction equation for poorly drained soils was:

$$CROWNCA = 3.62 + 10.61(SPCLA);\ r^2=0.56$$

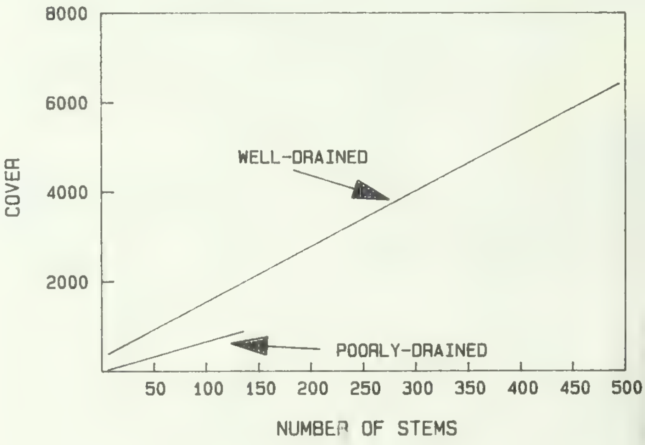

Figure 1.--Linear regressions of crown coverage pe acre on number of stems per acre for Coastal Plain oak coppice in 5-year-old pine plantations on well drained and poorly drained sites.

Table 6.--Average sprouting characteristics of individual sprout clumps and plantation by species

Oak species	Individual clump: Stems	Individual clump: Coverage	Plantation: Occurrence[1]	Plantation: Clumps	Plantation: Stems	Plantation: Coverage
	Number	-Ft^2-	-Percent-	- -acre- - Number/		Ft^2/ -acre-
Water	1.7	23.8	81	54	91	1280
Laurel	1.5	20.3	48	34	52	686
Bluejack	1.3	13.0	38	42	57	545

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[1] Percentage of 48 study plantations containing the respective oak species.

DISCUSSION

Differences in regressions between stages of development for all Piedmont species show that coppice of different ages cannot be compared on the basis of number of stems. Number of sprout stems will remain constant or decline while crown coverage increases. For a given age and species, however, we found very strong relationships between number of stems and crown coverage over a wide range of species. Furthermore, the relationships were not affected by harvesting treatments that were previously shown to affect competition from pine regeneration and residual stems (McMinn and Nutter 1988). Slopes ranged widely among species at both stages of development and there was little evidence that oaks could be grouped on a taxonomic basis. If application were confined to this study alone, there would probably be empirical justification for combining some species. However, there is no evidence that several Piedmont species could be grouped to assess coppice stands on the basis of a simple stem count. The one exception would be where species have approximately equal proportional representation among areas or treatments--a condition which was met in our particular study. Grouping is permissible under that condition because the average stem number-crown cover relationship would be similar among sample units.

Coastal Plain oaks present quite a different picture in the relationship of crown cover to number of stems. First, for the particular species studied, there is strong taxonomic as well as statistical justification for grouping. The three species are known to hybridize and are sometimes difficult to distinguish in the field (Little 1979). Also, number of stems appears to be a much weaker predictor of crown cover than in Piedmont species, accounting for only about half the variation on well-drained soils and slightly over 75 percent on poorly drained soils. The highly significant difference in the relationship of crown cover on number of stems between soil drainage categories signals caution in evaluating coppice by stem counts under varying site conditions--something for which we could not test with the Piedmont data. Finally, number of sprout clumps alone accounted for over half the variation in crown cover on both poorly drained and well-drained sites: number of clumps would be expected to approach number of stems as a predictor in species with so few average sprouts per clump.

CONCLUSIONS

The general question driving this study is, "Can we simply count sprouts in lieu of estimating crown cover when evaluating coppice regeneration?" The situations in which it would be legitimate to do so are relatively limited. With Piedmont species at a given age and on uniform sites it is appropriate for: (1) a single species, or (2) situations where species in mixtures are represented in approximately equal proportions among sample or experimental units. This study provides evidence that comparisons of sprout numbers across sites may be inappropriate for any species. For Coastal Plain oaks, use of sprout numbers is only appropriate if the investigator will accept an index that accounts for only about half the variation in crown cover on some sites.

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SURVIVAL AND GROWTH OF NATURAL AND ARTIFICIAL REGENERATION IN BOTTOMLAND HARDWOOD STANDS AFTER PARTIAL OVERSTORY REMOVAL[1]

Jim L. Chambers and Mary W. Henkel[2]

Abstract.--Survival and growth of underplanted seedlings, natural seedlings, and stump sprouts were measured two years after partial overstory removal treatments were applied to five stand types in southeastern Louisiana. Treatments included removal of 0, 12, 24, 36, 48, and 60 percent of the initial stand basal area for trees greater than 10 cm dbh. Survival was variable ranging from 45 to 99 percent for underplanted seedlings, from 72 to 90 percent for natural seedlings, from 89 to 98 percent for stump sprouts. Height growth was also variable but tended to increase with increasing overstory removal. Artificially and naturally regenerated seedlings had similar growth rates. However, rapid growth of stump sprouts at higher levels of overstory removal produced severe competition.

INTRODUCTION

Cutover, highgraded stands, stands in need of regeneration but with poor species composition, and sites where clearcutting is not a management option, represent problem areas common to bottomland hardwood forests of the South (Carvell and Tryon 1961, Chambers and others 1987). These areas often have stands with inadequate stocking in preferred species. Midstories and understories are often populated with large numbers of undesirable shade tolerant hardwoods and shrubs (Chambers and others 1987, Nix and others 1985, Tworkoski and others 1983). The means of producing adequate desirable regeneration have varied from clearcutting and planting to shelterwood systems. Problems with competition and poor initial species composition have led to varied results (Hodges and Janzen 1987). The objectives of this paper are to illustrate the impacts of understory control and partial overstory removal on: underplanted seedling survival and growth, survival and growth of natural regeneration, relative competitive ability of different regeneration types, and the potential performance of potential crop trees within each regeneration type for bottomland hardwood stands in Louisiana.

METHODS AND PROCEDURES

Study Areas

Five bottomland forest stands were located in four areas of south Louisiana. Two in East Baton Rouge Parish near Baton Rouge, one in East Feliciana Parish near Clinton, and two in Washington Parish near Franklinton. Selected stands had little or no history of management and were composed of trees with little commercial value. Overstory types in each stand were identified by importance value (Jenkins and Chambers 1989) of the overstory species based on relative basal area plus relative density of each species divided by 2 (table 1).

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Table 1.--Species composition and importance value of the five overstory types used in this study.

Overstory	Species	Importance value
American Beech-Swamp Tupelo-Spruce Pine (AB-ST-SP)	American Beech	24.74
	Swamp Tupelo	12.11
	Spruce Pine	10.53
	Sweetbay	9.70
	Water Oak	8.60
	Misc. (18 species)	34.30
		100.00
Swamp Tupelo-Sweetbay (ST-SB)	Swamp Tupelo	38.13
	Sweetbay	32.21
	Yellow-poplar	7.64
	Drummond Red Maple	7.49
	Misc. (7 species)	14.56
		100.00
Sweetgum-American Hornbeam (SG-AH)	Sweetgum	44.66
	American Hornbeam	21.11
	Yellow-poplar	6.10
	Water Oak	5.92
	Swamp Tupelo	5.03
	Misc. (18 species)	17.11
		100.00
Drummond Red Maple-Swamp Tupelo-Green Ash (RM-ST-GA)	Drummond Red Maple	26.54
	Swamp Tupelo	22.87
	Green Ash	17.25
	Sweetgum	9.08
	Sugarberry	6.60
	Misc. (15 species)	17.66
		100.00

Plot Establishment

Six 0.20-ha square treatment plots were established in each stand. All vegetation less than 10 cm d.b.h. was severed near ground line on all treatment plots. Partial overstory removal treatments consisted of removing 0, 12, 24, 36, 48, and 60 percent of the basal area from the plots. Care was taken to equally distribute basal area removal across the treatment plot. Jenkins and Chambers (1989) found that understory light levels after these overstory removal treatments averaged 7, 14, 23, 29, 39, and 45 percent respectively, of light levels in the open. After overstory treatments were applied ten 1-0 bare-root seedlings of sweetgum (Liquidambar styraciflua), green ash (Fraxinus pennsylvanica), Nuttall oak (Quercus nuttallii), and ten rooted-cuttings of green ash were planted at a 4.4 m spacing on the interior 0.1 ha of each treatment plot. This planting design provided a 7.0 m wide buffer strip around the edge of each measurement plot. Several other tree species were planted on the same plots a year later but will not be discussed in this paper.

Measurements

After one growing season for establishment, heights of all planted trees, stump sprouts (from trees larger than 10 cm DBH), pruned sprouts (from trees less than 10 cm DBH but greater than 30 cm tall were severed), and natural seedlings (seedlings and seedling sprouts) were measured prior to the second growing season and again at the end of the growing season. Least-likely comparison ratios were used to test for differences in survival and analysis of variance was used to test for growth differences. Natural regeneration was often insufficient to test by individual species so species were combined into three groups including: oak species Quercus sp., other desirable species, and undesirable species for analysis. The desirable species group included: Platanus occidentalis, Taxodium distichum, Prunus serotina, Tilia caroliniana, Ulumus sp., Fraxinus pennsylvanica, Carya sp., Diospyros virginiana, Celtis laevigata, Liquidambar styraciflua, Nyssa sylvatica var. biflora and Liriodendron tulipifera. The undersirable species group included: Fagus grandifolia, Melia azedarach, Osmanthus americanus, Acer rubrum, Ostrya virginiana, Halesia diptera, Oxydendrum arboreum, Magnolia grandiflora, Magnolia virginiana, Persia borbonia, and Cyrillia racemiflora.

RESULTS AND DISCUSSION

Survival

Survival of underplanted species ranged from 45 percent for sweetgum to nearly 89 percent for rooted green ash cuttings (table 2). Trends in survival across overstory removal levels were not apparent, but survival did differ significantly among some overstory types (table 3). Differences in survival among overstory types were probably caused by site factors (primarily flooding or poorly drained soils) or perhaps in some cases species conflicts (allelopathic effects). Sweetgum survival, for example, varied from a low of 21 percent on the partially flooded RM-ST-GA overstory type to a high of 71 percent on the well-drained AB-ST-SP site. Survival for all categories of natural regeneration varied from 50 to 100 percent (table 4). Survival differences were generally not significant by overstory type or overstory treatment level. Differences may have been masked since a wide variety of species were grouped together for statistical analysis.

Height Growth

Height growth of underplanted trees tended to increase with increasing levels of overstory removal. Differences across treatments were significant for all species combined and individually for rooted green ash cuttings (table 5). Similar trends of increasing height growth with increasing basal area removal were found for natural seedlings. Species groups

Table 2.--Underplanted seedling survival by species and level of overstory removal after two growing seasons

Category	Percent removal of the basal area						
	0	12	24	36	48	60	Total
Green ash							
Initial number of seedlings	50	50	50	52	50	50	302
Percent survival	82.0Aab[1]	68.0Ab	96.0Aa	79.0ABab	82.0Aab	82.0ABab	81.5A
Nuttall oak							
Initial number of seedlings	50	50	51	52	50	50	303
Percent survival	82.0Aa	74.0ABa	80.4Ba	69.2Aa	88.0Aa	72.0Aa	76.9A
Rooted green ash cuttings							
Initial number of seedlings	50	49	50	48	50	50	297
Percent survival	86.0Aa	81.6Ba	92.0Aa	89.6Ba	92.0Aa	92.0Ba	88.9B
Sweetgum							
Initial number of seedlings	50	50	49	50	50	51	300
Percent survival	54.0Ba	38.0Ca	49.0Ca	44.0Ca	42.0Ba	45.1Ca	45.0C
Total number of seedlings	200	199	200	202	200	201	1201
Percent survival	76.ab	65.3b	79.5a	69.3ab	76.0ab	73.0ab	73.1

[1] Least likely ratio comparisons were used to test for significant differences. Survivals with different capital letters are significantly (P > 0.05) different among species within a treatment (within a column); survivals with different lower case letters are significantly (P > 0.05) different among treatments within a species (across a row).

were significantly different among overstory treatment levels (table 5). The largest positive effects on height growth appeared to occur at overstory removal levels of 36 to 60 percent. This level of overstory removal provided average understory light levels just after cutting of 29 to 45 percent of that in the open (Jenkins and Chambers 1989).

Height growth did not differ significantly among treatments for either pruned sprouts or stump sprouts. However, the best height growth still occurred at either the 48 or 60 percent basal area removal level. The poorest height growth occurred at the lower overstory removal levels (table 5). Light levels on these plots just after treatment averaged less than 25 percent of that in the open (Jenkins and Chambers 1989). Data for all regeneration types suggest that between 0 and 60 percent basal area removal, increasing overstory removal results in increased height growth. The increased height growth with increasing levels of overstory removal may have been caused by, changes in understory light levels, changes in available nutrients or available water, and reductions in other competitive pressures or interactions among species.

Potential Crop Tree Growth

As in most regeneration situations many of the newly regenerated trees will not survive to be crop trees at the end of the rotation. Early dominance by a few individuals and persistence by some species will lead to a favoring of some individuals either by nature or by management decisions. Often the favored trees will be those of large stature and desirable species. Early height dominance may provide a clue as to the potential final crop trees and species composition or to management decisions which may be needed.

To examine the growth of early dominants of each species or species group by regeneration type, heights of the 10 tallest trees of each species (for underplanted species) or species group (for natural regeneration types) were averaged for each overstory treatment level. Figure 1 A-D depicts the average height trends for these top performers within each regeneration type. Of the underplanted species, green ash rooted cuttings, and Nuttall oak seedlings were the best performers averaging 150 to 220 cm of height at the higher overstory removal levels (fig. 1 A). Stump sprouts and

Table 3.--Underplanted seedling survival by species and overstory type after two growing seasons.

	Overstory type[1/]					
Category	AB-ST-SP	ST-SB	SG-AH	RM-ST-GA	SU-SG-BE	Total
Green ash						
Initial number of seedlings	60	62	60	60	60	302
Percent survival	83.3Aa[2/]	66.1Ab	88.3Aa	88.3Aa	81.6Aa	81.5A
Nuttall oak						
Initial number of seedlings	61	62	60	60	60	303
Percent survival	80.3Aa	48.4Bb	76.7Aa	90.0Ac	90.0Ac	76.9A
Rooted green ash cuttings						
Initial number of seedlings	60	57	59	60	61	297
Percent survival	95.08a	82.5Ca	88.1Aa	91.7Aa	86.9Aa	88.9B
Sweetgum						
Initial number of seedlings	59	60	60	61	60	300
Percent survival	71.2Aa	40.0Bab	56.7Ba	21.3Bb	38.3Bb	45.0Ca
Total number of seedlings	240	241	239	241	241	1202
Percent survival	78.8a	58.9b	77.4a	72.6a	74.3a	73.1

[1/] AB-ST-SP=American beech-swamp tupelo-spruce pine; ST-SB-Swamp tupelo-sweetbay; SG-AM=Sweetgum-American hornbeam; RM-ST-GA=Drummond red maple-swamp tupelo-green ash; and SU-SG-BE=Sugarberry-sweetgum-boxelder.

2/Least likely ratio comparisons were used to test for significant differences. Survivals with different capital letters are significantly (P > 0.05) different among species within an overstory type (within a column); survivals with different lower case letters are significantly (P > 0.05) different among overstory type within a species (across a column).

pruned sprouts of the oak species generally outgrew both natural seedlings and underplanted seedlings (fig. 1 B). For the other desirable and the undesirable species groups natural seedlings and pruned sprouts performed almost equally well, while underplanted seedlings were not far behind. However, stump sprouts outgrew all other regeneration types. Stump sprouts were more than twice as tall as other regeneration types (fig. 1 C-D). The large height differences between stump sprouts and other regeneration types suggest the distribution and number of potential stump sprouts will be an important consideration in planning for regeneration problems on bottomland hardwood sites.

CONCLUSIONS

Elimination of all understory tree and shrub vegetation (severing all woody stems less than 10 cm dbh near ground line) from treatment plots in five bottomland hardwood stands in southern Louisiana allowed evaluation of the effects of partial overstory removal treatments on survival and growth of artificial and natural regeneration. Survival of some underplanted species varied significantly by overstory type but not overstory removal level. Survival differences in underplanted species across overstory types emphasizes the need to match species to site. Survival of natural regeneration generally did not vary significantly with overstory type or overstory removal level. Species occurring as natural regeneration was probably appropriate for the sites on which they occurred. Moisture, nutrients and understory light levels on most plots were evidently sufficient for relatively high early survival of most bottomland hardwood species present as natural regeneration on these sites.

Height growth of both artificially and naturally regenerated species were however affected by partial overstory removal. Second-year height growth was generally greatest

Table 4.--Survival of natural regeneration by regeneration type, by species group and level of overstory removal.

Category	Percent removal of the basal area						
	0	12	24	36	48	60	Total
Natural Seedlings							
Oaks[1]							
Initial number of seedlings	72	64	63	34	44	79	360
Percent survival	89.5Aa[2]	89.1Aa	81.0Aa	94.1Aa	90.9Aa	96.2Aa	90.0A
Other desirable species							
Initial number of seedlings	81	90	105	131	108	93	608
Percent survival	60.9Ba	84.4Ab	71.4Aab	73.3Bab	68.5Bab	75.0Bab	72.4B
Undesirable species							
Initial number of seedlings	83	69	58	72	96	43	421
Percent survival	75.9Aa	85.5Aa	82.8Aa	79.6Ba	81.2Aa	86.0Ba	82.4C
Total number of seedlings	240	223	226	237	248	215	1389
Percent survival	75.0a	86.1a	77.0a	78.1a	77.4a	85.1a	80.0
Pruned Sprouts							
Oaks							
Initial number of sprouts	13	3	7	10	8	9	50
Percent survival	92.3Aa	100.0Aa	100.0Aa	100.0Aa	100.0Aa	100.0Aa	98.0A
Other desirable species							
Initial number of sprouts	11	8	13	8	18	10	68
Percent survival	100.0Aa	100.0Aa	100.0Aa	87.5Aa	88.9Aa	90.0Aa	92.6A
Undesirable species							
Initial number of sprouts	11	9	18	11	17	11	77
Percent survival	63.6Aa	77.7Aa	100.0Aa	90.9Aa	94.1Aa	100.0Aa	89.6A
Total number of sprouts	35	20	38	29	43	30	185
Percent survival	82.9a	90.0a	100.0a	93.1a	93.0a	96.7a	97.8
Stump Sprouts							
Oaks							
Initial number of sprouts	1	2	4	9	8	3	27
Percent survival	100.0Aa	50.0Aa	100.0Aa	100.0Aa	75.0Aa	100.0Aa	88.9A
Other desirable species							
Initial number of sprouts	6	19	34	39	42	53	191
Percent survival	83.3Aa	68.4Aa	94.1Aa	87.2Aa	85.7Aa	90.6Aa	87.0A
Undesirable species							
Initial number of sprouts	4	20	43	47	54	39	208
Percent survival	100.0Aa	85.0Aa	95.3Aa	89.4Aa	94.9Aa	94.9Aa	92.7A
Total number of sprouts	11	41	80	95	104	95	426
Percent survival	90.9a	75.0a	94.1a	89.5a	89.4a	92.6a	89.9

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[1] Oaks include *Quercus* spp.: Other desirable species include black cherry, Carolina basswood, elms, green ash, sugarberry, sycamore, tupelos, and yellow-poplar; Undesirable species include American beech, American holly, American hornbeam, boxelder, Chinaberry, devilwood, dogwood, red maple, sourwood, southern magnolia, swamp cyrilla, sweetbay, and two-wing silverbell.

[2] Least likely ratio comparisons were used to test for significant differences. Survivals with different capital letters are significantly (P > 0.05) different among species group within a treatment (within a column); survivals with different lower case letters are significantly (P > 0.05) different among treatments within a species group (across a row).

[2] Least likely ratio comparisons were used to test for significant differences. Survivals with different capital letters are significantly (P > 0.05) different among species group within a treatment (within a column); survivals with different lower case letters are significantly (P > 0.05) different among treatments within a species group (across a row).

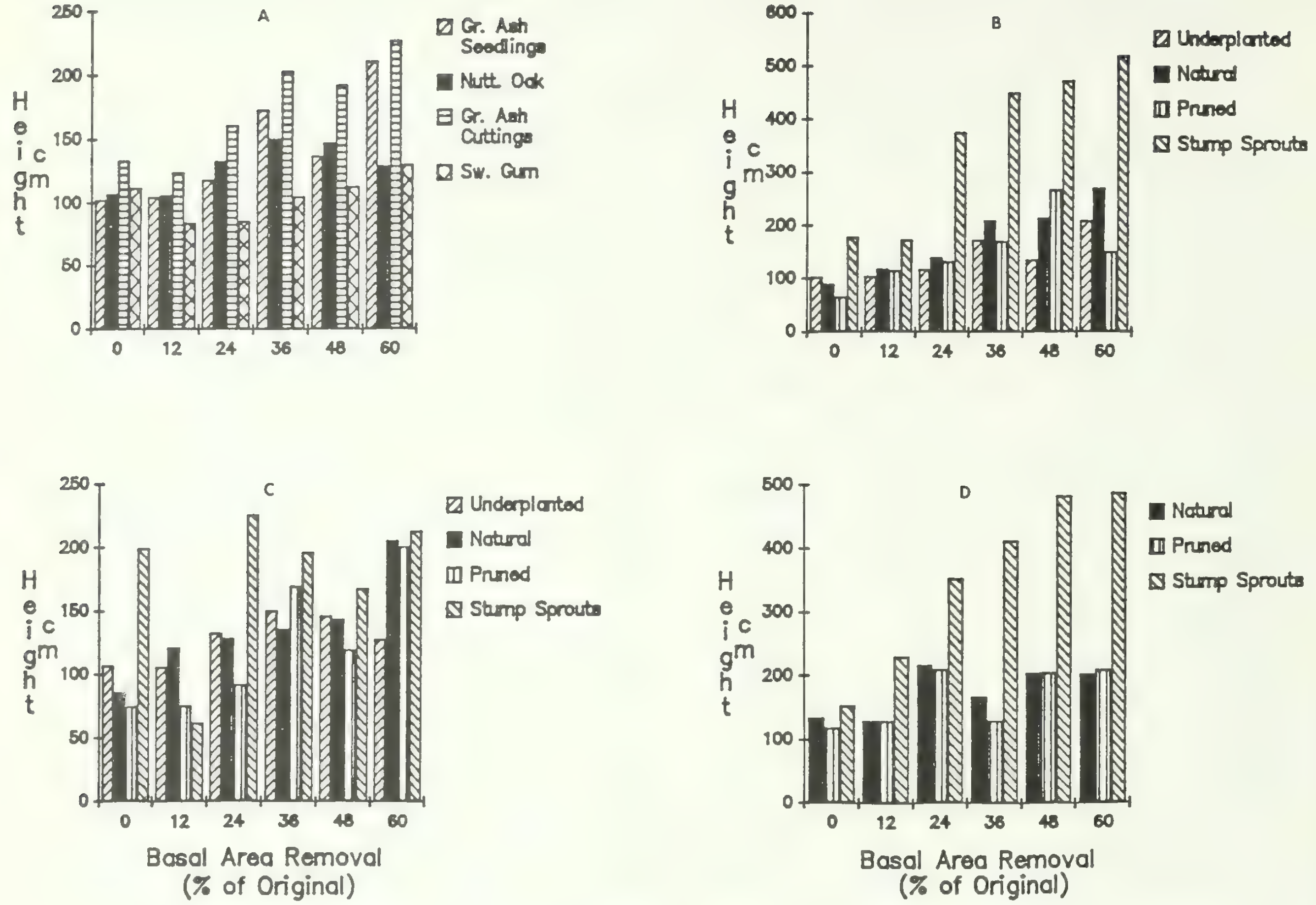

Figure 1.--Average height, by overstory treatment, of the 10 tallest individuals of each regeneration type, for each underplanted species (A), the oak species group (B), the desirable species group (C), and the undesirable species group (D), after two growing seasons.

obviously represent a desired form of regeneration. However, if large numbers of undesirable species will be present as stump sprouts a considerable barrier to other forms of regeneration will likely exist. A concerted effort will be required to control this form of regeneration problem.

New research is needed to confirm the effects of increased understory light levels on the growth of both natural and artificial regeneration of desirable tree species and to segregate the effects of light from the effects of nutrient and moisture supply changes. More research is also needed on the effects of stand composition on advanced regeneration of specific species.

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CULTURAL TREATMENTS FOR THE ESTABLISHMENT OF BOTTOMLAND HARDWOODS IN WEST TENNESSEE[1]

Allan E. Houston and Edward R. Buckner[2]

Abstract.--Green ash, sycamore, and sweetgum were established on abandoned agricultural bottomlands on the Ames Plantation with 150 pounds of elemental nitrogen and 35 pounds of elemental phosphorus per acre added at the beginning of the second growing season as a main treatment while disking and mowing were treated at the sub-plot level. After 5 years, height gains in disked plots versus control plots were 81 percent for green ash, 73 percent for sycamore, and 50 percent sweetgum. Height growth for green ash was 37 percent greater with fertilization alone; sycamore and sweetgum increased 29 and 15 percent respectively. Height growth was not affected significantly in mowing treatments. Gains in fertilizer treatments were confined primarily to the growing season following application.[3]

INTRODUCTION

Forests occupy 5.4 million hectares of land area in Tennessee with approximately 5.2 million hectares classified as commercial. Yet these figures are not static. Substantial fluctuations have occurred during recent decades. In 1960-61 there was a 9% increase in forested land due to marginal lands having reverted to trees during the previous decade. By 1971 this trend had reversed as forest clearing claimed more area than reforestation. Although the total area in commercial forest changed little from 1950 to 1981, 900,000 hectares shifted in and out of this classification (Callonne and Dujardin 1987).

Most new agricultural land from cleared forests is utilized for grazing (Callone and Dujardin 1987), however, a significant proportion of the land cleared along the Mississippi River and its tributaries in recent years has been to accommodate soybean production. Often this land is subject to flooding, and with economic forces acting to depress soybean prices, the increased risk of crop loss on these sites has led to abandonment of substantial land area formerly devoted to soybean production (Waldrop et al. 1982).

Without management these potentially highly productive lands often convert to low value timber species such as boxelder (*Acer negundo*), black willow (*Salix nigra*), and river birch (*Betula nigra* L.) (Waldrop et al. 1982). These sites provide opportunities for intensive forest establishment practices due to prior agricultural regimes which greatly enhance accessibility and on site maneuverability.

Land use changes are generally the result of dynamic forces, such as changing economic patterns, which provide the motivation for choice among possible land use alternatives. If these rich bottomland sites are to remain in a forested condition they must be able to compete favorably with other land use options in a constantly changing economic climate. Poorly stocked forests cannot do so. It is the purpose of this study to document the effects of a number of cultural treatments which may be used to establish desirable hardwoods on abandoned agricultural bottomlands in West Tennessee.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] Authors are indebted to the Hobart Ames Foundation which provided monetary support and land area to conduct this research.

METHODS

The study was conducted on the Ames Plantation which lies in the headwater basin of the North Fork Wolf River watershed, included in the tributary system of the Mississippi River. The watershed is located in the Mississippi Embayment section of the Gulf Coastal Plain physiographic province, 50 miles east of Memphis, Tennessee. Topography is characterized by rolling hills with broad flat floodplains. A layer of Pleistocene loess was deposited on top of fluvial materials. Erosion has removed much of the unconsolidated loess and fluvial deposits exposing more highly erodible sands in many upland areas. Recent alluvial deposits of sand, silt, clay, and fine gravel from upland sources are found in the floodplain areas of the watershed (USDA 1987).

The study site is located on soils in the Collins series, being moderately well drained, nearly level, acid soils along bottomlands and narrow drainageways (USDA 1964). The study site is characterized by recently deposited silt loam alluvium 12-18 inches thick overlying an older, poorly drained soil. Soil pH ranged from 5.4 to 6.6. Phosphorus and potassium levels were low for agricultural purposes (Waldrop et al. 1982).

As reported in Waldrop et al. (1982) four replications of green ash (Fraxinus pennsylvanica Marsh.), sycamore (Platanus occidentalis L.), and sweetgum (Liquidambar styraciflua L.) from the Virginia Coastal Plain and sycamore and sweetgum from the Louisiana Gulf Coast were established in the Spring of 1980 on recently abandoned agricultural bottomlands with 150 pounds of elemental nitrogen and 35 pounds of elemental phosphorus per acre broadcast at the beginning of the second growing season as a main treatment. Disking, mowing, and control treatments were tested at the sub-plot level in a split plot, randomized complete block design. The control treatment consisted of planting, but no follow up care. Disking and mowing were initiated immediately after establishment and applied 3 to 5 times each growing season.

Survival and tree heights (to the nearest .1 meter) were measured at the end of the fifth growing season following planting. All data were analyzed in a standard split plot analysis and mean separation was determined using orthogonal contrasts. Statistical significance was evaluated at the 95 percent confidence level.

Preliminary analysis of survival data indicated significant nonconformity to the normal distribution; therefore, in order to maintain the assumptions necessary for analysis of variance an angular transformation of the data was employed. Transformed data closely approximated the normal.

RESULTS

Survival

Survival was above 90 percent for all treatment combinations, which is remarkable considering the harsh summertime weather conditions during 3 of the 5 years. Among the 5 species/seed source combinations, green ash had the best survival (98.0 percent). There was no significant difference in overall survival of sycamore (92.5 percent) versus sweetgum (93.2 percent). There was no significant difference in survival between seed sources in either sycamore or sweetgum; therefore, seed sources within a species were combined. There was no significant difference in the survival of all species in fertilized (93.0 percent) versus unfertilized plots (95.0 percent). Among cultural treatments survival was best in the disking plots (97.0 percent), but no significant difference was noted in mowing (91.0 percent) versus the control (93.5 percent) treatments.

Height

Among the 5 species/seed source combinations, green ash (2.8 meters) was significantly shorter than the average for all other seed source combinations (3.8 meters). Overall, sycamore was significantly taller than sweetgum (4.5 meters versus 3.1 meters respectively). There was no significant difference in height growth between seed sources within sycamore or sweetgum.

Total height growth for all species was significantly greater in fertilized plots (fertilized = 3.8 meters versus nonfertilized = 3.3 meters).

Among cultural treatments height growth was greatly increased in the disking treatment (4.6 meters) as opposed to the average of the other two treatments (3.1 meters). There was no significant difference in mowing (3.1 meters) versus control (3.0 meters) treatments.

In addition, growth was analyzed from the beginning of the third growing season onward. Analysis of variance results regarding all treatments and relative standings closely paralleled those reported above, except for one major exception. Growth response in fertilized treatments was no longer significantly different from nonfertilized treatments.

DISCUSSION

Overall survival was excellent at the 5-year benchmark, with results very similar to those reported by Waldrop et al. (1982). These data demonstrate that fully stocked stands can be established on abandoned agricultural lands, even with harsh, droughty summertime conditions 3 out of 5 years after establishment, and point to the initial stages of establishment as being critical to the eventual success of the stand. Apparently seedlings which survive through the first two growing seasons have a credible chance to compete for space in the final stand. Cultural treatments which correlate well with increased height growth tend to provide increased early survival as well. Krinard and Kennedy (1981) reported similar response relationships for sycamore and green ash to mowing and disking after 5 years.

Figure 1 shows the relative average heights for each species and all cultural treatments. Height growth was not increased significantly for any species with mowing alone. Waldrop et al. (1982) reported that mowing tended to displace a naturally growing complex of competitive broadleaf weeds with seemingly more aggressive grass species. This change in the composition of competing vegetation was maintained through the fifth year and probably contributed to the inability of the seedlings to respond to the absence of overhead competition. In addition, repeated passes throughout the growing season with heavy equipment may have compacted the agricultural soils above the plow pan, impeding root development.

Height growth was increased in fertilization plots; but growth was not increased with the addition of mowing to fertilization. These data suggest fertilizers applied on these sites and very early in the development of the stand produce a growth surge confined largely to the growing season following application. Repeated fertilization may be less expensive in the long run than repeated visits to the site with heavy equipment as demanded by disking for example. Timing of application within the life of a stand (along with rate of application) may prove to be the crucial element in the development of feasible fertilization regimes.

Height growth in disked plots was significantly greater than all other treatments; and the addition of fertilization did not add significantly to these gains. With the limited root systems of these seedlings and the fact that fertilization effects tended to disappear after the second growth season, fertilizer effects superimposed over those of disking may have been masked by the seedlings response to removal of all competing vegetation and continual "fluffing" of the soil, which tended to increase moisture directly available to the seedlings. Although height gains in disked plots tended to accrue throughout the study, disking, unlike fertilization treatments, was accomplished every year.

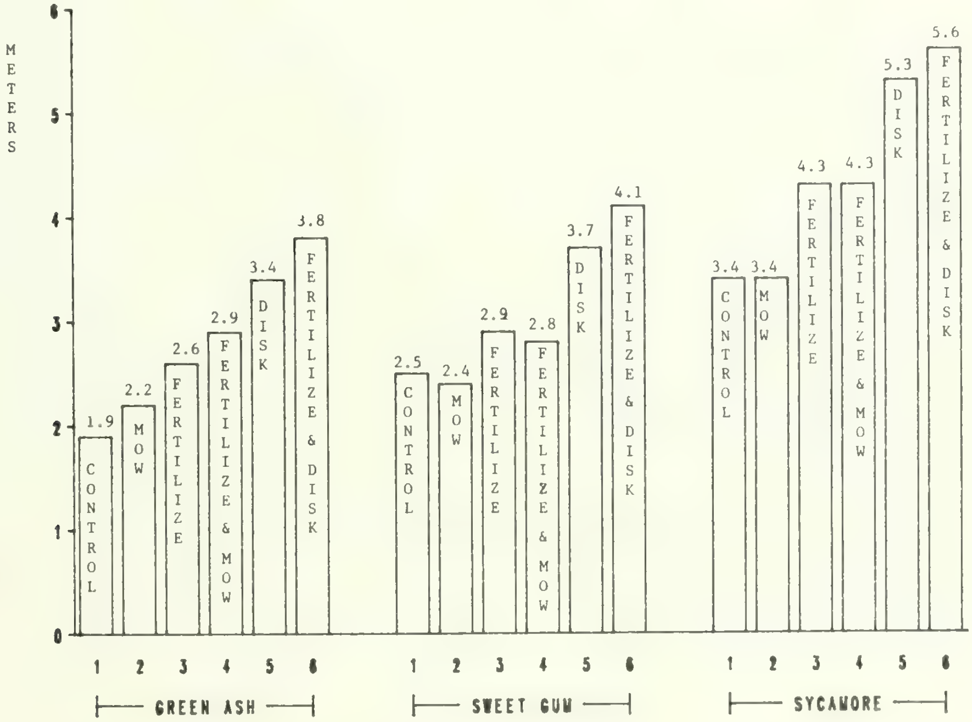

Figure 1. Fifth year mean heights of green ash, sweetgum, and sycamore grown under six different cultural treatments.

Disking to keep competing vegetation below acceptable levels is expensive. Vigilance is necessary or the trees can be lost from view below the tops of competing vegetation, further complicating application.

Even on the flat topography of the study site, one-way disking tended to appreciably increase erosion between rows, creating ridges where the trees were situated. It is not known if this has contributed to root systems largely confined in two dimensions. If so, increased risk of wind throw and decreased growth may result as the stand developes.

Results suggest that fully stocked stands can be established within a wide spectrum of management practices; however survival and height growth will be increased significantly with disking treatments applied several times per growing season and continued through the first five growing seasons (or until crown closure). Fertilization alone, applied at the beginning of the second growing season, should produce real gains in height; but these gains are largely developed in the growing season following application. Ultimately, maximum gains may be achieved by an admixture of cultural practices staggered strategically over the life of the stand and aimed not only at increasing productivity but attaining economic efficiency as well.

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Hardwood Management

Moderator:

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SELECTION THINNING IN SOUTHERN APPALACHIAN HARDWOODS[1]

Donald E. Beck[2]

Abstract.--In many parts of the Appalachians, harvest of trees below sawlog size returns a very low or even a negative income. Selection thinning, or thinning of dominants, to harvest merchantable trees and release smaller trees for future growth may be one limited management alternative to lessen the problem. In one case study, subdominant trees of varying size and relative position in the stand responded to release and developed into high-quality sawlog trees. Total yields were less 30 years after thinning than would be expected had the stand been thinned from below to favor the dominant trees. However, the earlier cash-flow and greatly reduced number of trees below sawlog size harvested under the method may make it an attractive alternative under some circumstances.

In the Southern Appalachians a combination of three circumstances requires us to examine a range of silvicultural options--some of which may be extraordinary or unorthodox. These factors are stand structure, landowner objectives, and market conditions. Most pole-sawtimber stands in the Southern Appalachians contain trees ranging from saplings and poles to large sawtimber. Some of the wide variation in size is due to differential growth rates among species. In other cases, trees of the same age and species differ widely in both diameter and height because some are of seedling origin while others are from either released advance growth or sprouts. In addition, past cutting practices created many two-aged stands. Whatever the causes, stands often contain numerous harvestable sawtimber trees along with many trees at or just below sawtimber size.

Private, nonindustrial landowners often want to harvest the merchantable trees as soon as a saleable quantity is available. A lack of markets for small roundwood usually translates into harvesting of sawlog-sized trees and leaving all smaller stems. The harvest may be a simple highgrade, or, at best, a diameter-limit harvest with little or no thought given to the future stand. A wide range of results is possible from this type of harvest. Probably most frequent is a stand laden with culls, poor-quality stems and less desirable species and greatly diminished productivity. In other cases, some of the subdominant trees may respond and, in conjunction with new reproduction, develop into an acceptable two-aged stand. And in some places enough subdominant trees, capable of growth response, are retained to form a fully stocked stand. The latter case could be considered a selection thinning or thinning of dominants since no regeneration is desired and the cut is made to foster growth of the residual stand of subdominants (Smith 1988). Any good results will be happenstance because attention is focused on what is being cut and not what is to be left. By focusing on what will be left, it may be possible to accommodate the owner's desire for immediate income from a sawtimber harvest and maintain the stand in a productive condition through some modification of an outright diameter-limit harvest. In this paper I consider a selection thinning, or thinning of dominants, as an alternative.

THE STUDY

This study is a part of a larger effort to evaluate a large number of diameter-limit cuts carried out from 1949 to 1954 on the Bent Creek Experimental Forest near Asheville, NC. These cuts were installed on a wide range of sites and over a variety of stand conditions. The harvest rules called for felling of all pine (*Pinus* spp.) 10.0-inches d.b.h. and larger with at least one 8-foot log with a scaling diameter of 8-inches inside the bark at the small end; all yellow-poplar (*Liriodendron tulipifera* L.), ash (*Fraxinus americana* L.), and basswood (*Tilia americana* L.) 11.0-inches d.b.h. with one 8-foot log with a scaling diameter of 8.0 inches; and all stems of other species 13.0 inches and larger with an 8-foot log with a scaling diameter of 12.0 inches. In 100-percent cruises made before and immediately after the harvest, stems were tallied by species in 2-inch diameter classes.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Tables 1 and 2 show stand structure and stand statistics immediately before and after the diameter-limit harvest cut. Prior to the harvest, the stand was carrying 107 square feet of basal area per acre in 175 trees per acre 6.0 inches d.b.h. and larger. Average tree diameter was 10.6 inches. The stand contained 12.7 mbf of volume. While many species were present, the stand was obviously dominated by yellow-poplar. The majority of trees other than yellow-poplar were in the smaller size classes.

The study reported here examined one 6.6-acre stand dominated by yellow-poplar on a very good cove site with an average site index of about 105 (Beck 1962). I determined the stand response 29 years after the harvest cut repeating the cruising methods used at the time of installation. In addition, I used complete stem analysis on all trees on a representative 1/4-acre plot to reconstruct the stand structure as it existed immediately after harvest and to examine the growth response of individual trees in relation to their initial condition. I then compared stand and tree responses to those expected under alternative management methods using existing growth and yield models (Beck 1974, Knoebel et al. 1986).

Table 1.--Number of trees per acre by diameter class before and after harvest

Species	<10	10-12	14-16	18-20	20+	Total
	Diameter class (inches)					
	Preharvest					
Yellow-poplar	31	39	24	3	1	98
Other	49	18	8	2	0	75
Total	80	57	32	5	1	173
	Postharvest					
Yellow-poplar	31	39	1	-	-	61
Other	49	16	3	-	-	68
Total	80	45	4	-	-	129

Table 2.--Number trees, basal area, volume per acre, and average tree diameter before and after harvest

Item	Trees	Basal area	Volume	Mean diameter
	Number	Sq. ft.	bd. ft.[1]	Inches
Preharvest	175	107	12,700	10.6
Cut trees	46	52	10,000	14.4
Postharvest	129	55	2,700	8.8

[1] International 1/4-inch rule.

For the most part, the marking rules were adhered to; only a few trees over the stated diameter limits were left. Yellow-poplar comprised about half the residual trees and slightly more than half the residual basal area. The cut removed nearly 80 percent of the volume and half of the basal area, but only about one-quarter of the trees. Average diameter was 14.4 inches for cut trees and 8.8 inches for residual trees.

RESULTS

Individual Tree Response

In order to characterize the type and condition of tree left after the diameter-limit cut I used the stem analysis data to determine past diameter and height and compared them to the distribution of those parameters in typical stands from growth and yield models. Figure 1 shows the height-diameter distribution of residuals compared to the expected distribution for a typical unthinned stand on a comparable site. In table 3 mean height and diameter by crown class for the current stand is shown in relation to the status of those trees following the harvest. The trees that dominate the current stand (the dominants and codominants) were the tallest residuals and for the most part were at least 70 percent as tall as the dominant stand. Only one of the sample trees that is currently a dominant or codominant was less than half as tall as the dominant stand prior

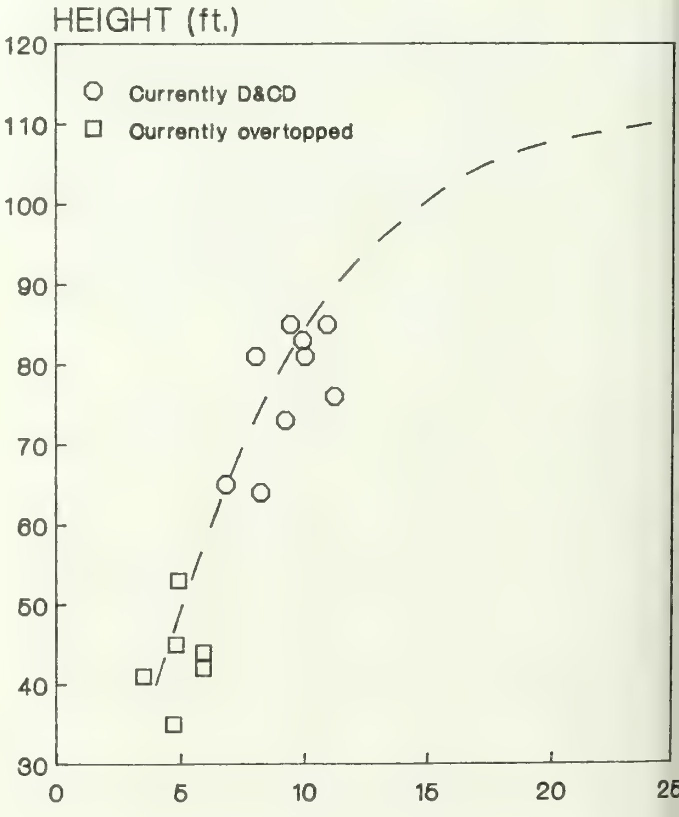

Figure 1.--Height-diameter distribution of residual trees following harvest.

Table 3.--Tree parameters by current crown class

Crown class	Current status Mean dbh	Current status Mean height	Postharvest status Mean dbh	Postharvest status Mean height	Postharvest status Mean age
	Inches	Feet	Inches	Feet	Years
Dominant	22.9	114	10.7	81	54
Codominant	15.2	110	8.2	71	49
Overtopped	8.7	67	5.3	40	32

to release. Based on distributions of crown classes by diameter in comparable unthinned stands, I surmise that the trees that formed the dominant new stand were mostly in the intermediate position before the harvest with, perhaps a few codominants. Although the residual stand is essentially in one age class, trees that are now dominant were larger in diameter and height and slightly older at time of release than were those that are now codominant. The trees that are currently in the intermediate and suppressed categories were much smaller trees when they were released, and they were, in fact, mostly from a younger age class. Clearly, we were dealing with a two-aged stand: the predominant stand was about 50 years old but it contained a 30-year age class that probably originated from an earlier diameter-limit cut. None of this younger age class was able to achieve a position in the main canopy in the 29 years after the harvest cut.

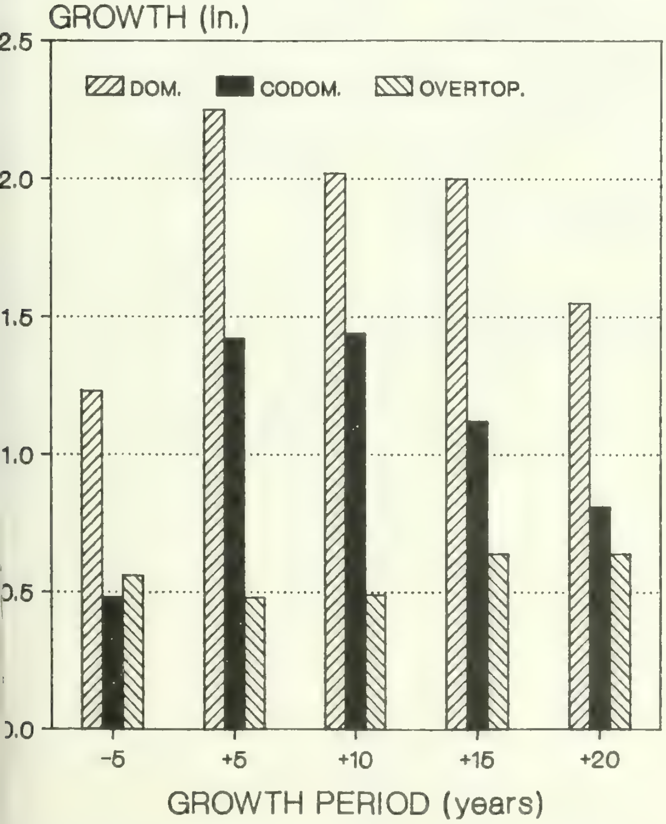

Figure 2.--Five-year diameter growth by periods before and after the harvest cut by current crown class.

Figure 2 compares diameter growth rate by 5-year periods after release to the rate immediately before release. The trees are grouped by the crown class ultimately attained. In addition to being taller and larger in diameter prior to release, the trees that eventually became dominants were growing more than twice as fast as those that became codominant or were overtopped. After release, the dominants-to-be nearly doubled their diameter growth rate in the first 5 years. Codominants-to-be nearly tripled their growth rate but still grew at a slower absolute rate than the dominants-to-be. Apparently, the trees that are currently overtopped were comparable in vigor to the current codominants at the time of release but were too small, relative to their competitors, to better their position.

Stand Yield

Stand growth and yield for the diameter-limit cut are compared to expected growth and yield had the stand been thinned from below (table 4). Growth of the stand during the 29 years after the diameter-limit cut was about 69 percent of what we would expect had the stand been thinned from below following recommended practices. Standing volume at the end of the period was only 53 percent of that expected from a thinning from below. However, the total stand yield including the earlier thinned volume from the diameter-limit cut was 81 percent of the total expected for a stand thinned from below. There is major difference, however, in how the volume yields are distributed over time. About 36 percent of the total yield was harvested in the selection thinning, whereas sawtimber volume harvested in the hypothetical thinning from below was only 2 percent of the total and was not an operable cut. In thinning from below, 100 trees smaller than sawlog size with 20 square feet of basal area would have been cut. In the diameter-limit option, only 20 such trees with 5 square feet of basal area were cut.

Table 4.--Stand yields under two management alternatives

Item	Thin from below[1]	Thin dominants[2]
	-------Board feet--------	
Preharvest	12,700	12,700
Cut	700	10,000
Postharvest	12,000	2,700
Growth	21,700	15,000
Current	33,700	17,700
Total production	34,400	27,700

[1] Residual basal area = 80
Trees = 79
Mean d.b.h. = 14.0

[2] Residual basal area = 55
Trees = 129
Mean d.b.h. = 8.8

DISCUSSION AND CONCLUSIONS

This case study of diameter-limit harvest in one yellow-poplar stand on a good cove site suggests that there are opportunities to use selection thinning to generate income and at the same time maintain the stand in a reasonably productive condition. Trees from the dominant crown classes that were on average only 70 percent as tall and 65 percent as large in diameter as those trees removed, responded vigorously and developed into large, high-quality sawtimber. Due to the way in which many Appalachian hardwood stands originate and develop, trees in subordinate crown classes are not necessarily of low vigor. In this instance, the 129 residual trees with 55 square feet of basal area per acre were able to grow at only 69 percent the rate we would have expected from a more conventional thinning from below. But total yields including thinning volume was 81 percent of that expected after conventional thinning. At the same time, thinning of dominants provided substantial income from 10 mbf of sawtimber much earlier in the rotation. It also necessitated the removal of far fewer trees below sawtimber size. Modification of the thinning to leave more basal area would have undoubtedly increased total stand growth after thinning. Leaving additional trees to avoid holes in the stand also presumably would have improved the growth after thinning. But we can only speculate on the impact on total yield and income.

As Smith (1988) has pointed out, selection thinning should be applied with caution. It is very easy to slip over into highgrading, particularly if the method is attempted more than once in the life of a stand. I view selection thinning as a way to take advantage of a particular circumstance on a limited basis. If done correctly, with discretion, and an eye for the residual stand, it can be an acceptable silvicultural prescription that meets owner objectives for income and maintains the stand in a productive condition, at least on a one-time basis.

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EARLY PRUNING OF YOUNG PECAN TREES AFFECTS GROWTH AND BOLE QUALITY[1]

John R. Toliver and Steve Dicke[2]

Abstract.-- Artificial pruning may improve stem quality but it's effects on early growth are unknown. This study was designed to compare pecan stem growth and quality in an unpruned control with annual prunings (ages 3-6 yrs)and one pruning at age 6.5 yrs. In addition, a P and K fertilizer treatment was evaluated. Fertilization increased height and diameter growth by 42% after 5 yrs. Pruning resulted in creating 235 pecan trees/acre with at least a 6- to 12-ft clear bole versus 0/acre on the control at age 8 years.

INTRODUCTION

Sweet pecan (*Carya illinoensis* (Wangenh.)
. Koch) is one of the most commercially valuable
ottomland hardwood trees in the South. Its
atural range extends from southern Indiana,
llinois, and Iowa south to lower Louisiana, and
estward from eastern Mississippi and Tennessee
nto central Texas and Oklahoma. Isolated
opulations are also scattered in Ohio,
entucky, Alabama, and central Mexico (Fowells
965). Because of the value of its nut, pecan
s widely planted across the South and pecan
rchards are quite common in many southern
tates.

Pecan is one of the largest native
ickories in the United States reaching heights
f 140 ft and diameters of 2-4 ft (Clark 1973).
he growth rate is considered medium to good
hen compared to other hardwood species (Sparks
977). Nelson (1965) reported that average
en-year diameter growths of pecan in an
nmanaged stand ranged from 1.9 to 2.7 inches
epending on the diameter class. Putnam et al
960 state that free-to-grow pecan trees 6
nches d.b.h or greater grow at a rate of 2.60
o 3.60 inches over a 10-yr period. In
ouisiana pecan timber has become a valuable
ommodity for veneer and lumber in the
anufacture of furniture, cabinets and paneling. Pecan stumpage value in mixed hardwood stands averaged $72/mbf Doyle scale in Louisiana in 1988 (La. Dept. of Agric. and For. 1988). However, large quantities of high quality pecan logs have been known to sell for upwards of $700/MBF. Thus, pecan logs can be a valuable source of income to many landowners in the state.

Pecan trees growing in natural stands will usually grow tall and straight and produce high-quality saw logs, but pecan is not commonly found in large numbers in dense stands. Open-grown trees are usually very limby and often have short poor-quality trunks, making them unmarketable for good saw logs. Pecan trees in nut production orchards are usually planted at wide spacing to hasten crown expansion and early nut production. When orchards reach over-maturity and need to be reestablished, the boles of these trees are usually of insufficient length to be sold as saw logs. These trees are often piled and burned or sold for firewood. If orchard-grown trees were pruned to a height of 10-12 ft before crown expansion is allowed, high quality pecan saw logs could be sold at the time of orchard turnover. Similarly, plantation-grown pecans could be pruned at an early age, thereby improving log quality in many trees. Thus, at 40-50 yrs the plantations could be harvested for saw or veneer logs, producing a relatively large source of income for the land owner.

METHODS

The plantation used for this study was intially established in 1980 on an old-field site in southeastern Louisiana near Clinton (Meadows 1981 and Meadows). The soils were classified as Cascilla and Calhoun silt loams, somewhat fertile and moderately well-drained. Estimated site index for pecan was 88 ft at age 50 yrs. Spacing was 10 X 10 ft and four replications of 120 trees each were planted. At 2 yrs of age 1/2 of the plantation was fertilized with 200 lbs/ac of P and K (0-24-24).

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[1] Paper presented at Fifth Biennial Southern
ilvicultural Research Conference, Memphis, TN,
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Initially, the plantation was established to assess the response of pecan to six methods of seedling establishment (Meadows 1981 and Meadows and Toliver 1987). This pruning study was established within the plantation at age 3. With one exception, no differences in height existed among establishment methods at the time (Meadows and Toliver 1987).

A split-split plot design was used for the pruning study. The fertilized and unfertilized treatments served as the main blocks and each of three pruning treatments was randomly assigned to a sub-plot within. A pruning treatment sub-plot consisted of twelve 5-tree-row plots. Pruning treatment 1 was a control where no pruning was performed. Treatment 2 included an annual pruning in the late winter or early spring (1983, 84, 85, and 86). Treatment 3 involved a single pruning at 6.5 yrs of age in 1986. The objective of pruning was to establish and maintain a clear 8- to 12-ft bole in each tree as soon as possible. Trees were usually severely pruned, leaving less than 1/3 of the live crown. In addition corrective pruning was applied to remove forks in order to establish a straighter bole. Measurements were taken at ages 3, 5 and 8 yrs and included total height, clear bole length, and diameter at 4.5 ft (dbh).

RESULTS AND DISCUSSION

Fertilizer

Fertilizing with 0-24-24 significantly increased diameter by age 5 yrs (table 1) and height by age 8 yrs (table 2). Soils of the type these trees were planted on are quite often deficient in phosphorus. Meadows (1981) analyzed the soils in this plantation and found them to be low in extractable P (12 ppm) and K (17 ppm). Soil analysis was not performed at any time after fertilization; therefore, we do not know how much the extractable P and K was increased. However, it was apparently sufficient to increase the vigor and growth of the pecan substantially as the fertilized trees were 42% taller and 43% larger in diameter at age 8 yrs.

Pruning

Pecan trees which were pruned annually were 23% smaller in diameter than the undpruned or single-pruned trees (table 3). This was not unexpected as these trees were severely pruned prior to leaf out every year for four years. They most likely utilized stored food to rebuild photosynthetic surface and very little photosynthate would have been left for diameter growth. No significant differences in dbh were noted between the control and single-pruned trees.

Table 1.--Effect of fertilizer on diameter of sweet pecan

	Age		
Treatment	3 yrs	5 yrs	8 yrs
		Dbh (in)	
Unfertilized	----	0.70a*	1.76a
Fertilized	----	1.05b	2.51b

* Values having common letters within a column are not significantly different.

Table 2.--Influence of fertilizer on height of sweet pecan

	Age		
Treatment	3 yrs	5 yrs	8 yrs
		Height (ft)	
Unfertilized	2.25a*	4.62a	11.81a
Fertilized	2.95a	6.79a	16.77b

* Values having common letters within a column are not significantly different.

Table 3.--Effect of pruning on diameter of sweet pecan

	Age		
Treatment	3 yrs	5 yrs	8 yrs
		DBH (in)	
No pruning	----	0.82a*	2.40a
1 pruning	----	1.13a	2.36a
Annual pruning	----	0.88a	1.94b

* Values having common letters within a column are not significantly different.

On the other hand, a single pruning resulted in the tallest trees, followed by the controls and annual pruning (table 4). The significant height increase of the single-pruned trees over the control trees, coupled with non-significant differences in diameter between the two treatments, indicates that the pruning is accomplishing its purpose. Height growth has been stimulated without decreasing diameter growth. Thus, a larger, clearer bole is developing at a relatively young age.

Fertilization combined with pruning improved the potential quality and productivity of the stand by a wide margin over the control by the eighth year. Each tree was classified by log length and clearity. As demonstrated in table 5, the control plots had no trees with at least a 6-ft clear bole, whereas fertilization with annual or a single pruning resulted in more than enough potential quality crop trees to manage to the end of a 40- to 60-year rotation.

Table 4.--Effect of pruning on height of sweet pecan

	Age		
Treatment	3 yrs	5 yrs	8 yrs
	Height (ft)		
No Pruning	2.59a*	5.50a	14.85a
1 Pruning	2.68a	5.84a	15.87b
Annual pruning	2.60a	5.82a	13.39c

* Values having common letters within a column are not significantly different.

Table 5.--Potential number of logs in young pecan trees resulting from treatments

	Number of logs/acre					
	Fertilized Number prunings			Unfertilized Number prunings		
Log length	0	1	4	0	1	4
6 ft	0	94	84	0	68	44
8 ft	0	43	84	0	26	8
10 ft	0	94	50	0	8	8
12 ft +	0	14	16	0	0	0
Total	0	245	234	0	102	60

Considering all characterisitics, fertilization and a single pruning at 6.5 yrs of age created the most potential for developing a high-quality stand. Trees under this combined treatment averaged 18.3 ft tall, 2.8 in dbh, 7.4 ft of clear bole, and 35% of the trees had developed at least an 8-ft clear log (table 6). On the other hand, trees in the control were half as large in all characteristics (table 6), and none had clear boles. As the potential crop trees grow and develop, thinning will need to be employed to allow room for crown expansion and maximum diameter growth. Once a good clear log is established the stand can be opened up to increase nut production and enhance growth.

CONCLUSIONS

Three-yr-old sweet pecan trees responded well to P and K fertilization. Pruning young pecan trees at an early age produced a large number of potential high quality crop trees. Annual pruning from age 3 yrs on resulted in clear boles but, decreased growth when compared to no pruning or pruning once at age 6.5 yrs No pruning resulted in no clear boles at age 8 yrs. A single pruning at age 6.5 yrs resulted in more trees with potential clear logs. Fertilization, with a single pruning at age 6.5 yrs, resulted in the tallest trees, largest diameters, and most trees with potential high-quality logs.

Table 6.--Summary of characteristics of 8-yr-old pecan trees subjected to fertilization and pruning.

	Fertilized Number prunings			Unfertilized Number prunings		
	0	1	4	0	1	4
Height (ft)	16.5	18.3	15.7	13.5	11.7	9.9
Dbh (in)	2.7	2.8	2.3	2.2	1.8	1.4
Clr bole (ft)	2.6	7.4	7.0	2.4	5.0	4.2
No. 8-ft+ Logs/acre	0	152	152	0	34	8

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FLOODING, STAND STRUCTURE, AND STAND DENSITY AND THEIR EFFECT ON PIN OAK GROWTH IN SOUTHEASTERN MISSOURI[1]

Robert Rogers and Ivan S. Sander[2]

Abstract.--Twenty-year diameter and basal area growth of young pin oak stands subjected to two flooding and six thinning treatments were evaluated in the Mingo Basin of southeastern Missouri. Dormant season flooding did not significantly inhibit basal area growth. However, stand structure and density did affect basal area growth rate differently over time. Properly thinned stands can benefit both timber and waterfowl production.[3]

Pin oak stands in southeastern Missouri riverbottoms normally flood 1 to 4 times per year for 2 to 10 days each time. But in some areas, called green tree reservoirs, this riverbottom land is purposely flooded from mid-November until the end of January to attract migrating waterfowl. Because it is flooded only in the dormant season, trees are not killed. Although the primary management goal for green tree reservoirs is to provide and improve waterfowl habitat, an important secondary goal may be to grow trees for timber products.

In 1956, we began a study to determine the effects of flooding, stand density and stand structure on stand growth, acorn production, and regeneration in a green tree reservoir and in comparable naturally flooded 30-year-old pin oak stands in the Mingo Basin of southeastern Missouri. Reported earlier were 8-year growth (Minckler 1967), acorn production (Minckler and McDermott 1960, Minckler and Janes 1965, McQuilkin and Musbach 1977), pruning effects (McQuilkin 1975), and form class (Jensen and Woerheide 1956). This paper reports on 20-year diameter and basal area growth.

METHODS

This study was conducted in southeastern Missouri in the Mingo Basin, which is a wet lowland formed on an abandoned channel of the Mississippi River.[4] The soils in the basin are poorly drained, gray alluvial silt loams of the Waverly series (Miller and Krusekopf 1929). The tree species in this area are primarily bottomland oaks--pin (Quercus palustris Muenchh.), willow (Q. phellos L.), overcup (Q. lyrata Walt.), and cherrybark (Q. falcata var. pagodaefolia Ell.).

The experiment was designed as a split plot with whole plots consisting of flooding treatments and split plots consisting of density and structure treatments. Eighteen 0.5-acre plots were set up within a green tree reservoir in the Missouri Department of Conservation Duck Creek Wildlife Management Area and were purposely flooded during the winter months. Low levees contained 1 to 3 feet of water until drained through manmade ditches. A similar number of plots were located in the USDI Fish and Wildlife Service Mingo National Wildlife Refuge and received only occasional natural flooding. Trees on the study plots were 25 to 35 years old in 1956.

Stand structure and density were altered by thinning the 0.5-acre plots within flooded and normal areas. Thinning treatments consisted of all combinations of two levels of stand structure (thinning from above to create a small tree structure and thinning from below to create a large tree structure) and three levels of stand density (40, 60, and 75+ ft^2 of basal area per acre). Three replications of six treatments assigned at random to plots in both the flooded and normal areas provide a total of 36 plots for analysis.

In the spring of 1956 plots were thinned by frilling and herbiciding. All treated trees died the first summer. The plots were rethinned in the spring of 1964 to basal areas of 40, 65, and 90+ ft^2 per acre. During each thinning, well formed pin oaks were favored over other species as much as possible while still satisfying stocking structure requirements and maintaining good spacing throughout the plot.

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[1] Paper presented at Fifth Biennial Southern Silviculture Research Conference, Memphis, TN, November 1-3, 1988.

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[3] Cooperators in this study are the University of Missouri, the Missouri Conservation Commission, and the U.S. Fish and Wildlife Service. Special thanks go to Alan Black, Research Associate, University of Missouri, for his constructive criticism of the manuscript.

[4] McCrea, E. J. 1972. Inventory of interpretive resources -- Mingo National Wildlife Refuge. Unpublished report. U.S. Department of Interior, U.S. Fish and Wildlife Service, Mingo National Wildlife Refuge, Puxico, Missouri.

Before stands were thinned in 1956, tree diameter at breast height (d.b.h.) (4.5 feet above ground level) was measured with a diameter tape to the nearest 0.1 inch. Trees remaining in the stand after thinning were tagged and d.b.h.'s were remeasured at 2-year intervals until 1964 and at the end of the 1969 and 1975 growing seasons. Plot basal areas were calculated for all trees more than 4.5 inches d.b.h. initially and after each remeasurement. These data were subsequently used to estimate basal area growth rates. Thus, we have basal area and diameter growth data for a 20-year period spanning stand ages from 30 to 50 years.

To determine 20-year net basal area growth of residual trees on each plot, we subtracted plot basal area in 1956 after thinning from that in 1964 before thinning and added it to the difference between residual basal area in 1964 and final basal area in 1975. We used analysis of covariance to test the hypotheses that flooding, structure, and stand density had no effect on 20-year net basal area growth in pin oak stands after the effect of pretreatment basal area was removed. The rates of basal area growth on each plot were estimated by linear regressions of plot basal area on time since thinning for the period between the first and second thinnings and for the period after the second thinning to the end of the study. Analysis of variance was used to test the hypothesis that flooding, structure, and stand density had no effect on on the rate of basal area growth for either period.

Diameter growth of trees surviving the 20-year period was averaged for each plot. These averages were also subjected to analysis of variance.

To determine how basal area and d.b.h. of crop trees respond to thinning treatments and site conditions, we summed basal area and calculated average diameter at age 30 and again at age 50 using the 20 largest trees per plot (40 trees per acre) at age 30. We used an ANOVA to test the hypothesis that basal area and average diameter of these 20 trees at age 30 were the same for all treatments. Then we subjected basal area and average d.b.h. at age 50 to an analysis of covariance using basal area and average d.b.h. at age 30 as covariates so that the treatment responses at age 50 could be evaluated independently of plot to plot variations in initial basal area and average d.b.h.

RESULTS

After the first thinning, trees 11 inches d.b.h. or greater accounted for 64 percent of the basal area in large tree plots and only 25 percent of the basal area in small tree plots. Average d.b.h.'s were 8.0 and 9.3 inches for small and large tree plots, respectively. The basal area in residual stands on the flooded plots was 88 percent pin oak and 12 percent overcup oak and other species and on the normal plots was 60 percent pin oak, 19 percent willow oak, and 21 percent overcup oak and other species.

After the second thinning, trees more than 13 inches d.b.h. accounted for 50 percent of the basal area in large tree plots and 20 percent of the basal area in small tree plots. Average d.b.h.'s were 9.7 and 11.5 inches for small and large tree plots, respectively. The percentage of basal area in species other than pin or willow oak was greater on high or moderate density plots than on low density plots because there was less opportunity to remove these species during the second thinning. Less than 2 percent of total basal area on low density plots was composed of species other than pin, willow, or overcup oaks while these species comprised 11 percent of total basal area on moderate or high density plots. However, species composition differed little between artificially flooded and normal areas.

Net basal area yield at age 50 differed between flooded and normal sites, among density levels, and between structure classes but this was mainly due to differences in basal area on plots before they were thinned (fig. 1). Therefore, we first used covariance analysis to remove the affects of pretreatment basal areas before we analyzed treatment affects on basal area growth, rate of basal area growth, and diameter growth. Including pretreatment basal area as a covariate in the analysis significantly ($p < 0.05$) reduced the error sums of squares associated with the split-plot but not the whole plot. Therefore, we adjusted responses affected by density and structure for pretreatment basal areas but did not adjust those affected by flooding.

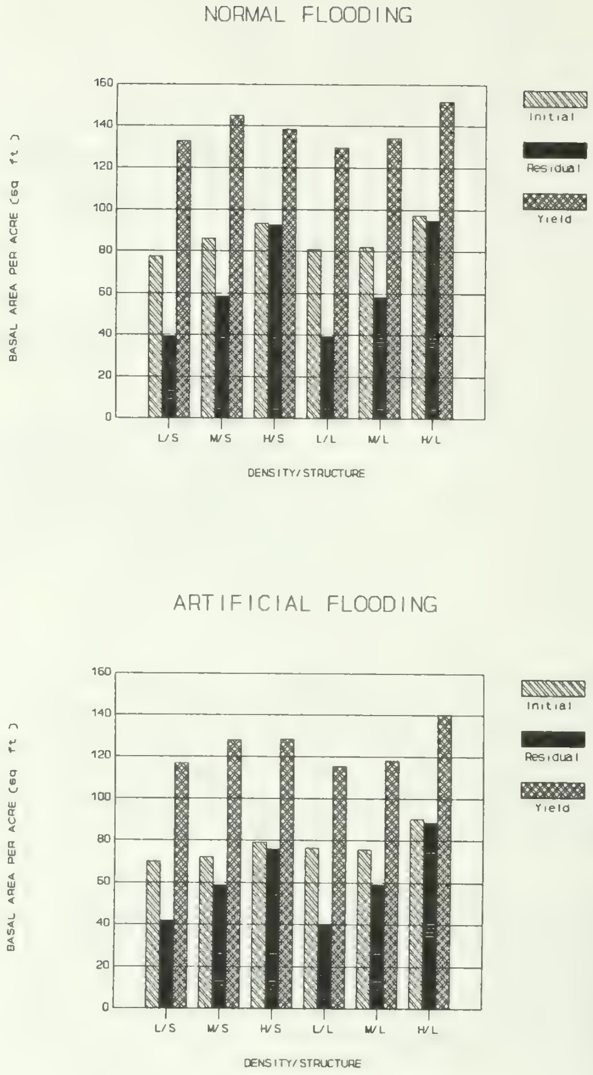


Figure 1.--Basal area per acre before and after initial thinning at age
and net basal area yield per acre at age 50 in stands thinn
to low, moderate and high densities with small and large t
stand structure. [Density: L=low, M=medium, H=high
Structure: S=small tree, L=large tree]

Among the three factors investigated in this study, only structure
a significant ($p < 0.05$) effect on 20-year basal area growth. The pl
thinned to leave small trees (thinned from above) increased their ba
area by approximately 53 ft^2 per acre compared to 46 ft^2 per acre for pl
thinned to leave large trees (thinned from below). The flooding eff
was nonsignificant ($p > 0.05$) even though naturally flooded stands gr
10 percent more in basal area than artificially flooded stands.

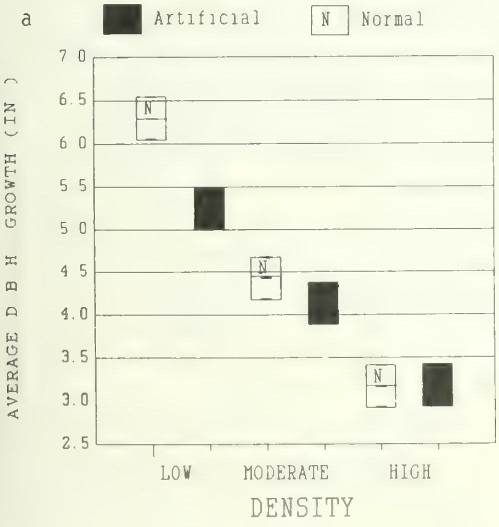
The factors that most affected basal area growth rates differed w
thinning periods. After the first thinning, stand density significantly (p
0.05) affected the rate of basal area growth and after the second thinni
stand structure significantly ($p < 0.05$) influenced the rate of basal a
growth. After the first thinning, moderately thinned plots had the high
basal area growth rate (3.066 ft^2/a/year) while lightly thinned plots h
the lowest basal area growth rate (2.456 ft^2/a/year). After the seco
thinning, basal area increased significantly ($p < 0.05$) faster in small t
plots (2.458 ft^2/a/year) than in large tree plots (2.077 ft^2/a/year).

Twenty-year diameter growth (average growth of surviving trees on a plot) was influenced by residual stand density and structure. Not surprisingly, the effect of stand density on diameter growth was highly significant ($p < 0.001$). Plots thinned the heaviest had the greatest diameter increase and those thinned the lightest had the smallest diameter increase. However, the extent of the diameter increase depended on whether the stands were subjected to natural or artificial flooding (fig. 2a). In heavily thinned stands diameter growth differed significantly between natural and artificially flooded sites while in lightly thinned stands it was about the same on both sites. Diameter growth in heavily thinned, normal plots was 6.3 inches as opposed to 5.3 inches for heavily thinned, artificially flooded plots.

Large tree plots averaged more d.b.h. growth than small tree plots, but again the amount of growth depended on whether they were naturally or artificially flooded (fig. 2b). D.b.h. growth differed little between small and large tree plots on artificially flooded sites but on normal sites it was an average of 0.7 inches more on large tree plots than on small tree plots.

Average diameters for the largest 40 trees per acre were 8.8 to 13.3 inches at age 30 and were 14.2 to 18.6 inches at age 50. The sum of the basal areas of the largest 40 trees per acre was 17.7 to 38.9 ft^2 at age 30 and was 44.9 to 76.0 ft^2 at age 50. Analysis of variance of these crop trees at age 30 indicated that their average d.b.h. and basal area per acre did not differ significantly between artificially flooded and normal sites (11.1 versus 10.9 inches and 27.7 versus 27.0 ft^2, respectively). However, average d.b.h. and basal area per acre did differ significantly ($p < 0.05$) between small and large tree plots and among stand density levels. Average diameters were 10.3 and 11.7 inches for small and large tree stand structures, and 9.7, 11.2, and 12.1 inches for low, moderate, and high stand densities. Corresponding basal areas per acre were 23.6 and 31.1 ft^2 for small and large tree stand structures, and 21.6, 28.0, and 32.4 ft^2 for low, moderate, and high stand densities.

Interestingly, the pattern of tree responses at age 50 was the same as at age 30 except that average d.b.h. and basal area per acre no longer differed among density levels. Apparently, thinning to different density levels differentially accelerated d.b.h. growth so that by the end of the 20-year period the variation in average d.b.h. and basal area was reduced to insignificance. This same result was obtained even when d.b.h. and basal area responses at age 50 were adjusted for the differences observed in average diameter and basal area at age 30. Including initial average diameter or initial basal area as a covariate did not significantly reduce error variance in the analysis. Diameters averaged 16.2 inches and basal area per acre averaged 58.9 ft^2. Crop trees in small tree plots had an average diameter of 15.4 inches and a basal area per acre of 53.1 ft^2. Crop trees in large tree plots had an average diameter of 17.0 inches and a basal area per acre of 64.8 ft^2.



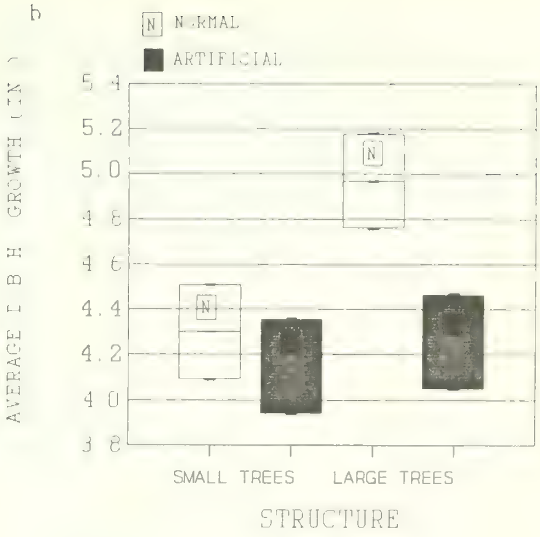


Figure 2.-- Effects of flooding and density and flooding and structure on average stand diameter growth. Window plot shows mean (bar) and honest significant confidence interval ($p = 0.05$). The honestly significant difference procedure (also called Tukey's w-procedure) was used to calculate intervals. Non-overlapping window plots are significantly different.

Thus, of the three factors investigated in the 20-year study (flooding, structure, and density), only residual stand density affected average d.b.h. and basal area of the selected crop trees--it equalized the differences in average d.b.h. and basal area observed at the outset of the experiment.

DISCUSSION AND RECOMMENDATIONS

Pin oak stands designated as green tree reservoirs often are managed to provide both wildlife and timber resources. However, silvicultural treatment of pin oak stands necessary to provide food, water, and cover for waterfowl migrating along the lower Mississippi Flyway could alter timber production objectives of treated stands.

Data collected from a study of 30-year-old pin oak stands thinned twice during a 20-year period did not give sufficient evidence to show that flooding stands purposely during the dormant season significantly inhibits their diameter and basal area growth. However, we observed that stands subjected to natural flooding grew 10 percent more in basal area than stands purposely flooded during the dormant season. We recommend that additional studies be made of flooding and its affect on pin oak.

Despite the reduced basal area in areas flooded during the dormant season, production of sound acorns was not impaired. McQuilkin and Musbach (1977) found that prolonged flooding during their dormant season does not decrease the production of sound pin oak acorns. They recommended that stand density be kept high and large trees be retained in preference to smaller trees to maximize acorn production on artificially flooded areas. Even if flooding does significantly reduce basal area growth of residual trees following thinning, the reduced basal area growth would be offset by the creation of suitable waterfowl habitat that otherwise would be absent.

We recommend light thinning from below to leave large trees on artificially flooded sites to enhance acorn production and growth of crop trees. Although stand basal area growth was greater in stands thinned from above, the increment was distributed over a greater number of smaller trees so that average stand diameter growth was actually less (though not significantly) than in plots thinned from below. And when only crop trees were considered, basal area and average diameter were greater in stands thinned from below than those thinned from above.

Stands thinned as heavily as those represented by the lowest residual density in this study have no advantage for increasing either basal area growth or waterfowl food. We recommend flooding young pin oak stands during the dormant season but basal area growth on residual trees may be slightly reduced in stands thinned twice over a 20-year period. Greatest gains in basal area and d.b.h. growth of selected crop trees will occur in stands thinned from below. Stands thinned to 70 to 90 square feet of basal area per acre will result in an average of 78 trees per acre whose d.b.h. is greater than or equal to 11 inches at age 50.

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EARLY RESPONSE OF A MIXED OAK-GUM-PINE STAND TO IMPROVEMENT CUTTINGS[1]

Stephen G. Dicke, Norwin E. Linnartz, and
Joseph R. Clifton[2]

Abstract.--Following three types of improvement cuttings (timber, wildlife, and timber-wildlife combination), basal areas of undamaged high-quality stems were similar to that in an uncut control. Harvesting was profitable, but large losses from skidder damage occurred. Dbh and basal area growth of residuals was greater following cutting than in the control.

INTRODUCTION

The southern bottomland hardwood forest is potentially one of the most productive areas in North America for timber (Smith and Linnartz 1980) and for a variety of birds and mammals (Byrd 1981, Glasgow and Noble 1972). However, actual production of timber and wildlife often is disappointing. Stands are typically dominated by malformed stems and undesirable species which take up growing space that could be supporting valuable timber and mast-producing trees. Murphy (1975) estimated that 96% of the hardwood stands in Louisiana need some type of silvicultural treatment to improve the stocking of desirable stems.

The pole stage of stand development is a period of intense tree competition and high tree mortality rates. Therefore, this is the best time to apply silvicultural treatments in hardwood stands to improve timber production (Kellison et al. 1981, McKnight and Johnson 1980). Low light levels at the forest floor during this stage result in limited wildlife food and cover (Gardiner 1988). Openings in the canopy are needed to provide adequate browse, mast and cover for wildlife needs (Harlow and Van Leer 1987, Wolters et al. 1982).

One of the most common silvicultural practices employed in previously unmanaged hardwood stands is an improvement cutting. The purpose is to improve the composition and quality of stands in the pole stage of development or older (Smith 1986). Cuttings can be flexible and designed to meet specific management objectives such as timber production, wildlife habitat improvement or both. But, there is a general lack of information on the appearance, composition, and structure of stands following a cutting, which has caused hesitation in the use of improvement cuttings. Therefore, in this paper we describe changes in stand characteristics as a result of three kinds of improvement cuttings: one designed to maximize timber production, another to maximize improvement of wildlife habitat, and the third being a compromise to improve both timber production and wildlife habitat. Timber aspects will be emphasized in this paper; wildlife benefits from these improvement cuttings are discussed by Gardiner (1988).

MATERIALS AND METHODS

Stand description

The study is located within the Idlewild Research Station near Clinton, LA on a terrace of Sandy Creek, a minor stream. The soils are fertile, moderately well to poorly drained silt loams of the Bude, Calhoun, Cascilla and Providence series. Site index (50 yrs) is about 110 ft for pines and 90 ft for red oaks (Clifton 1987).

The stand was two-aged; most of the hardwood stems were 30 yrs of age, but scattered throughout the stand were veteran pines 60-70 yrs old. The stand developed on an abandoned pasture in the early 1950's and much of the study area was burned prior to 1959. Therefore, a large portion of the stand is of hardwood sprout origin following fire. Stocking in 1986 was heavy, averaging 130 ft^2/ac of basal area (BA) and a density of 235 trees/ac. Red oaks predominated, but white oaks, sweetgum, and pines were also present in the stand (table 1).

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988. Approved for publication by the Director of the Louisiana Agricultural Experiment Station.

[2] Instructor and Professor, School of Forestry, Wildlife, and Fisheries, Louisiana State University, Baton Rouge and Land Acquisition Forester, Union Camp Corp., Prattville, AL.

Table 1.--Species composition in a natural pole-sized oak-gum-pine stand

Genus	Species[1]		Percent of Basal Area
	Common Name	Scientific Name	
Quercus			68
	cherrybark oak	*Q. falcata* var. *pagodifolia* Ell.	
	obtusa oak	*Q. obtusa* Ashe.	
	water oak	*Q. nigra* L.	
	willow oak	*Q. phellos* L.	
	total red oaks (57% of BA)		
	swamp chestnut oak	*Q. michauxii* Nutt.	
	post oak	*Q. stellata* Wangenh.	
	white oak	*Q. alba* L.	
	total white oaks (11% of BA)		
Liquidambar			17
	sweetgum	*L. styraciflua* L.	
Pinus			12
	loblolly pine	*P. taeda* L.	
	shortleaf pine	*P. echinata* Mill.	
	spruce pine	*P. glabra* Walt.	
Miscellaneous			3

[1] Little (1979) used as authority for scientic names except for obtusa oak where Vines (1960) was used.

Study design

Three types of improvement cuttings were tested. The first was designed to improve timber production by providing growing space for potential high-quality sawtimber. The second was designed to improve wildlife habitat by providing room for crown development of mast-producing trees and creating small openings for browse and cover production without regard for timber quality. The third type of cutting, a timber-wildlife compromise, was designed to combine the goals of the first two cuttings. A comparison of the three types of cuttings based on the kind of trees favored or cut follows. Healthy, vigorous codominants and dominants that were good mast-producing species and had high-quality stems were residuals in all three types of cutting. Many of the larger red oaks were in this category. Conversely, weak, inferior, off-site or decadent trees (suppressed, small oaks and older pines) were removed in all cuttings. Mast-producing culls (oak and pine) were removed from the timber plots, kept in wildlife plots, and half were cut and half left in timber-wildlife plots. Non-mast-producing trees with high-quality stems, such as sweetgum, were kept in timber plots, removed from wildlife plots, and half were removed and half kept in the timber-wildlife plots.

A randomized incomplete block design with four replications was used. The 65-ac stand was divided into fourteen 4.7-ac rectangular plots, each with a 2.5-ac measurement plot surrounded by treated buffer strips. Plots were grouped by BA into four blocks, averaging 124, 110, 104, and 101 ft^2 BA/ac. Each improvement-cutting type was applied to one of the plots within each BA block; due to space limitations an uncut control was included only in the high- and low-BA blocks. Timber marked for removal was harvested during March-June 1986. Trees were cut, limbed and bucked with chainsaws. Tree-length pulpwood and sawtimber were then removed from the plots with rubber-tired skidders and pulled to loading decks.

Measurements

All residual trees within each 2.5-ac measurement area plot were tagged before cuttings were made. Dbh was measured above the tag to the nearest 0.04 in. (1mm) with diameter tapes during the winter of 1985-86 (before cuttings), and measurements were repeated the following two winters. Therefore, the period of measurement was 2 yrs, but the response time after cutting was only 1.5 yrs.

The harvesting operation caused damage and mortality to residuals. Most mortality occurred from felling and skidding operations, but some pine trees were killed the second year by pine bark beetles attracted to the area by logging slash. Rubber-tired skidder movement in the stand and their removal of logs also resulted in numerous tree boles being skinned. The sizes and locations of these wounds were recorded for each residual tree.

Residuals were grouped into five tree classes based on their potential to produce valuable timber in the future (table 2). These tree classes are used by Anderson Tulley, Vicksburg, MS (Fred Newcomb, Pers. Commun.) and are a refinement of Putnam et al. (1960) classification. The tree classes of primary importance to the future value of the stand were the preferred, reserve, and bolt classes, since they are expected to produce valuable sawtimber and pulpwood. The cut and cull tree classes are not expected to add any future value to stands, and would, in fact, be removed in a timber improvement cutting. Some culls were kept in the wildlife and timber-wildlife cuttings, as stated before, for mast production. Therefore, description of the status and growth of the preferred, reserve and bolt classes, hereafter referred to as the select tree classes, will be stressed.

Analysis of variance was used to test for differences among cutting treatments in 2-yr dbh growth in select tree classes. Differences among cutting treatments in 2-yr BA growth, mortality, ingrowth, and net increment were also tested by tree class. Treatment variation in

Table 2.--Tree classes based on potential future value (developed by Anderson Tulley, Vicksburg, MS)

Tree Class	Characteristics
Preferred	1. Good condition, suitable for site. 2. Dominant or codominant. 3. Desired species for sawtimber. 4. Meets minimum log-grade standards: dbh 16+ in. with 16 ft of grade 1 or 24 ft of grade 2 dbh <16 in. with potential for above log grades.
Reserve	1-3 same as above. 4. Meets or potentially can meet grade 3 standards.
Bolt	1. Same as above. 2. Has or will have 8-ft pulpwood stick.
Cut	1. Poor condition, off-site, decadent. 2. Currently valuable but will probably die in the near future.
Cull	1. No merchantable value.

the above tests was partitioned into a cutting treatment versus control contrast to determine if cuttings, in general, had any early effect on growth. Although differences in the above characteristics were not statistically significant ($p=.05$), definite trends are indicated and are discussed in the results.

RESULTS

Harvest yields

Harvesting in this pole-sized stand was only marginally profitable because of low volumes per acre and most of the yield was pulpwood. Average pulpwood yield was 3.3 cords/ac, of which 85% was hardwood. The veteran pine, up to 33 in. dbh, made the harvest profitable. Sawtimber yields averaged 900 bd ft/ac, of which 90% came from pine. This mixture of species and products resulted in very low volumes/ac of pine pulpwood and hardwood sawtimber. Value of the 1986 harvest ranged from \$100 to \$120/ac depending on the amount of pine sawtimber removed from a plot.

Logging Damage

Mortality caused by the harvest operation averaged 1.6 ft^2 of BA/ac over the 2-yr study period (table 3). This was offset by less natural mortality, making 2-yr mortality losses in cut plots similar to losses in the control.

Table 3.--Basal area of damaged trees and mortality following improvement cuttings

Damage and Mortality	Control	Improvement Cutting
	ft^2/ac	
Skinned up Bole		
on butt-log	-	5.6
on stump	-	6.1
total	-	11.7
2-yr Mortality		
logging-caused	-	1.6
natural	2.6	1.5
total	2.6	3.1

Skidder damage to the boles of trees was the most serious problem. Trees totaling 12 ft^2 of BA/ac were skinned on the butt log or the stump (table 3). This amount of damage, almost 17% of the total residual BA and 25% of the stems, is fairly typical for rubber-tired skidders. Response of trees to damage and stems developing rot will be monitored in the future.

Residuals

On the average, all three cuttings removed 40% of the total BA, with most removals coming out of the cut tree class (table 4). The BA in damaged trees was listed separately from the select tree classes, because these trees have the potential for loss from rot. The percentage of residual BA in the select classes was over 80% for timber and wildlife improvement cuttings (table 4). The timber-wildlife cutting had a lower percentage of select class BA, 73%, as a result of higher amounts of damage. This percentage was still higher than the control, which had only 55% of total BA in select tree classes. Trees in the preferred, reserve, and bolt tree classes averaged 12.3, 11.2 and 6.4 in. dbh, respectively. There were also

Table 4.--Residual basal area by tree class following improvement cuttings

Tree Class	Control	Improvement Cutting		
		Timber	Wildlife	T-W
		ft^2/ac		
Preferred	12.6	10.4	13.2	11.6
Reserve	39.8	38.2	32.0	26.7
Bolt	13.9	13.3	12.2	10.3
Total Select	66.3	61.9	57.4	48.6
Cut	45.8	-	-	-
Cull	8.5	-	5.2	2.8
Damaged		12.3	8.7	15.4
Total	120.6	74.2	71.3	66.8

differences among cutting treatments in residual BA of culls (table 4), which reflects whether mast-producing culls were kept or removed from a cutting treatment.

Diameter Growth

Diameter growth of trees in the select tree classes was higher the first 1.5 yrs following improvement cuttings than in the control (table 5). Cuttings increased growth of all diameter classes almost 0.05 in./yr over that found in the control. The largest trees (15-25 in. dbh) in the treated plots were growing at about 0.25 in./yr, well below the expected growth rate of 0.40 in./yr for managed hardwoods 14-18 in. dbh (Putnam et al. 1960). Given more time to respond, these trees may reach the expected growth rate.

Table 5.--Diameter growth of trees in select tree classes by diameter class the first 1.5 yrs following improvement cuttings

Diameter Class	Improvement Cutting			
	Control	Timber	Wildlife	T-W
in.	0.1 in./yr			
5	0.5	0.8	0.8	1.1
10	1.2	1.5	1.6	1.7
15	1.8	2.1	2.4	2.4
20	2.2	2.6	2.3	2.3
25	1.6	2.6	2.0	2.6
Average	1.1	1.3	1.4	1.6

Basal area changes

Growth, expressed as a % of initial BA, was almost 50% higher after cutting than in the control (table 6). Mortality (%) was higher in cut plots, but this was offset by twice as much ingrowth. The timber-wildlife cutting had the highest mortality and also the highest growth rate. As a result, net BA increment (%) following all three types of cuttings were similar to that in the control. Since this is an early response to cutting, the cut plots should have higher increments than the control in the future.

BA growth of trees in the select tree classes was higher following cuttings (table 7). Preferred tree class BA growth was 15% higher in cut plots than in the control. In addition, improvement cuttings increased reserve and bolt class BA growth 40% over the control. Higher BA growth rates were found in timber-wildlife cutting plots than in timber (table 7), which was due to the lower residual BA following timber-wildlife cuttings (table 4). The wildlife cutting was intermediate in residual BA and BA growth. This indicates that the initial growth response to an improvement cutting increases as residual BA decreases.

Table 6.--Annual basal area changes the first 1.5 yrs following improvement cuttings

Basal Area Change	Improvement Cutting			
	Control	Timber	Wildlife	T-W
	% of residual basal area			
Growth	4.0	5.7	5.7	6.3
Mortality	2.2	4.3	4.7	5.1
Ingrowth	0.4	0.9	1.0	1.0
Net Increment	2.2	2.3	2.0	2.2

Table 7.--Annual basal area growth by tree class the first 1.5 yrs following improvement cuttings

Tree Class	Improvement Cutting			
	Control	Timber	Wildlife	T-W
	% of residual basal area			
Preferred	3.3	3.8	3.8	3.8
Reserve	2.4	3.0	3.0	3.2
Bolt	1.8	2.5	2.8	3.2
Cut	1.7	-	-	-
Cull	1.1	-	0.8	3.0

SUMMARY

Three types of improvement cuttings (timber, wildlife, and timber-wildlife) were applied in a pole-sized, mixed oak-gum-pine stand on a minor stream terrace in LA. Improvement cuttings removed many of the low-value trees that would have died before final harvest and provided an early income. Plenty of high-quality timber (50-60 ft^2 BA/ac) was left in the stand for future growth, even with significant skidder-damage losses. Room for growth was provided for the preferred, reserve and bolt tree classes by a 40% reduction in stand basal area. Diameter and basal area growth were higher following cutting, even after only 1.5 yrs of response. Since the stand initially contained many high-quality oaks, stand characteristics following the three cutting treatments were very similar. As a result, all three cuttings appear to be equally good for timber production.

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A FINANCIAL COMPARISON OF SHORT AND LONG TIMBER ROTATIONS ASSOCIATED WITH TWO PATTERNS OF CHERRYBARK OAK DEVELOPMENT[1/]

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Abstract.--An assessment of the future value of oak timber when converted to grade lumber and discounted to the present at real rates of interest was used to compare the financial desirability of two patterns of cherrybark oak (Quercus falcata var. pagodifolia Ell.) development. Oaks with a restricted developmental pattern had longer rotations but higher board-foot production than those with an unrestricted pattern. At optimal rotation ages, both patterns provided similar present net worths at real interest rates of 2 to 5 percent. However, differences in present net worth between the two patterns of development increased when discounting rates were 6 percent and above, making the shorter rotation of the unrestricted pattern more financially attractive.

INTRODUCTION

Is long-rotation hardwood forestry for sawlogs financially attractive? Generally, few timber operations actually have managed hardwood stands for sawlogs over an entire rotation from regeneration to harvest. Most stands that have been harvested had regenerated and developed naturally with little human intervention and with little active forest management. Thus, reliable data on the development of hardwood stands over an entire rotation from which to base a financial analysis are difficult to obtain.

In a previous study of mixed, even-aged bottomland hardwood stands on old fields in central Mississippi, reconstruction techniques were used to trace the development of cherrybark oak (Quercus falcata var. pagodifolia Ell.) (Clatterbuck and Hodges 1988). Individual cherrybark oak trees were observed to develop in either an unrestricted or a restricted pattern (table 1). The unrestricted pattern consisted of open-grown cherrybark oaks with little competition from adjacent trees, thus promoting large crowns at an early age, short bole lengths, and fast diameter growth rates. Cherrybark oaks under the unrestricted pattern of development averaged 22 inches in d.b.h., 85 feet in height and 24 feet in clear bole length after 40 years. The restricted pattern of development occurred at narrow spacings where competition from adjacent trees promoted long, straight cherrybark oak boles that were free of branches to a height of 50 feet by age 60. Due to the competition for growing space with adjacent trees, a longer time was required for these cherrybark oaks to attain large diameters. Cherrybark oaks in the restricted pattern of development averaged 24 inches in d.b.h. and 112 feet in height after 60 years. The development of each form of cherrybark oak, open-grown versus restricted growth, probably caused the differences in height growth between patterns (table 1). These height differences were not due to differences in site quality. Other differences between the two patterns of cherrybark oak development occurred in the timing of crown expansion, the length and subsequent volume of the clear merchantable bole, and the diameter growth rates.

Cherrybark oak occurs on moist, well-drained, alluvial floodplain terraces and loess deposits of the Atlantic and Gulf Coastal Plains and the lower Mississippi Valley. Because of its fast growth, its branch-free straight bole, and its subsequent high value for quality factory lumber, cherrybark oak has been called "the best red oak" (Putnam and others 1960) of the bottomlands. These high quality oaks often have value ratios of 13:7:1 for log grades 1, 2, and 3 (Stubbs 1986), indicating that the better log grades are more profitable.

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Table 1.--Physical development of the two forms of cherrybark oak

Age	Height	Diameter at 4.5 ft	No. of clear 16-ft logs	Log grade 1st log	 2nd log	 3rd log	Board Foot Volume (Int 1/4-in)
-yrs-	--ft--	---in---					
			Restricted pattern				
30	76	9	2	3	3	-	63
35	84	12	2	3	3	-	98
40	91	14	2.5	2	3	3	164
45	97	16	2.5	1	3	3	233
50	103	19	2.5	1	2	3	332
55	108	21	3	1	2	3	528
60	112	24	3	1	2	3	644
65	116	27	3	1	1	3	836
70	120	29	3	1	1	3	977
			Unrestricted pattern				
25	69	13	1	3	-	-	59
30	75	16	1	3	-	-	98
35	80	19	1.5	2	3	-	222
40	85	22	1.5	1	3	-	304
45	89	24	1.5	1	3	-	368
50	93	26	1.5	1	3	-	436
55	97	28	1.5	1	3	-	510
60	101	30	2	1	3	-	758

Our objective in this paper is to compare the financial desirability of the two forms of cherrybark oak, including potential real price increases and alternative uses of the land. The evaluation consists of determining the value of oak timber, in 1987 prices, when converted to lumber and discounted to the present at an appropriate rate of interest.

PROCEDURES

The fundamental question we wish to answer is how can one maximize the present net worth from even-aged stands of cherrybark oak. Three analyses were used to evaluate this question:

1. Lumber value of cherrybark oak for two forms of development.
2. Lumber value of cherrybark oak for two forms of development with potential cherrybark oak price increases.
3. Value of alternative uses of the land.

In our analysis we consider different real interest rates and different stand ages. Real interest rates were used here instead of market rates because costs, prices, and the rate of inflation are difficult to predict 50 years into the future (Hotvedt 1982). One should be aware of whether interest rates are real or market rates when comparing investments (Gregersen 1975). We assume no initial costs because most of the stands occur where old fields have naturally reforested. There may be costs associated with acquiring and/or holding the land, but these costs are not included in the analysis. The analysis looks at 5-year intervals of cherrybark oak development. Readers should consider that short-term fluctuations in lumber prices may influence the optimal harvest date within any 5-year period.

Analysis 1 - Two Forms of Cherrybark Oak

This analysis requires determining, for each pattern of cherrybark oak development, the amount of oak timber volume that has accumulated at 5-year age intervals, the lumber grade yield of that timber volume, and the value or price in 1987 dollars of that lumber. The board-foot volumes (International 1/4-inch log rule) are from the tables of Mesavage and Girard (1946) using form class 80. The lumber grade yields, or the percentage of lumber by grade that is cut from a particular grade log, were estimated from the red oak tables by Hanks and others (1980) (table 2). The value (1987 dollars) of the lumber was determined by averaging lumber price quotations from five hardwood mills in Mississippi and Alabama. The average base price for first and seconds (FAS) red oak lumber was $1,200 per thousand board feet (MBF) and the prices for #1 common, #2 common, and #3 common lumber were calculated as 70 percent, 40 percent, and 25 percent of the FAS base price, respectively. The value of the tree is the sum of the lumber values of its merchantable logs. That sum represents the value in present day prices of lumber contained within a cherrybark oak tree at a particular age and is discounted to the present by the formula:

$$PNW = Vt / (1+i)^{t} \qquad (1)$$

where PNW = present net worth (dollars),

V = value in 1987 dollars expected in time period t,

i = real interest rate (without inflation), and

t = age (years).

The optimal rotation age for cherrybark oak is the age where PNW is maximized.

Table 2.--Percentage of lumber in each log grade for red oak logs across all diameters[1/]

Log Grade	Lumber Grade[2/]			
	FAS	#1C	#2C	#3C
1	36.4	30.8	12.8	19.9
2	11.4	32.9	21.3	34.2
3	2.0	21.2	26.8	50.0

[1/] Source: Tables 49-51 in Hanks and others 1980).

[2/] First and seconds (FAS) and select ercentages were combined into one class. #1C = 1 common lumber, #2C = #2 common, and #3C = #3 ommon.

A sample calculation for a 20-inch, 16-foot, grade 1 log containing 144 board feet is illustrated in table 3. The lumber grade yield percentage multiplied by the total board feet contained in the log gave the number of board feet in that lumber grade. That product was then multiplied by the price per board foot of that lumber grade to yield the value of lumber of that grade contained in the log. The value of the log was the sum of the values of each lumber grade.

Analysis 2 - Potential Cherrybark Oak Price Increase

The effect of cherrybark oak lumber price increases on the valuation conducted in Analysis 1 is assessed in Analysis 2. The form of the cherrybark oak remains an important consideration because tree form influences the value of the tree at any given age. Two different price changes were considered: one where all grades of cherrybark oak lumber increase at equal rates and another where only FAS lumber shows a real price increase. A price increase of 2 percent per year was used to determine PNW in both cases (Hoover 1985).

Analysis 3 - Alternative Land Uses

This analysis is used to evaluate the optimal management strategy, given that there is another land use with a known soil expectation value. The manager must determine the optimal time to convert the land to an alternative use. The manager is faced with two alternatives: convert to the alternative use immediately or after the cherrybark oak has reached financial maturity. The equation used to evaluate this problem is:

$$PNW = [(Vt*s) / (1+i)^{t-c}] + [a / (1+i)^{t-c}] \qquad (2)$$

where c = current age of the stand (years),

t = optimal harvest age of the stand (years),

a = soil expectation value of alternative land use (dollars/acre), and

s = stocking rate (trees/acre),

PNW, V, and i -- refer to equation (1).

Equation 2 consists of two known values that are discounted to the time during the rotation when the evaluation is made. The first set of terms in brackets is the discounted value of lumber in the stand. The second set of terms in brackets is the discounted value of the alternative land use. When the PNW from equation 2 is greater than a, the known value of the alternative land use, the manager should harvest the timber at optimal age t. If not, then the cherrybark oak should be harvested immediately and the land used for the alternative purpose.

Table 3.--Total log value as partitioned by lumber grade for a 20-inch, 16-foot, grade 1 cherrybark oak log containing 144 board feet

Lumber grade	Lumber grade yield (%) for a grade 1 log[1]	Board foot Volume (Int 1/4-in)	Price per board foot	Total value
			dollars	dollars
FAS	0.364	52.4	1.20	62.90
#1C	0.308	44.4	0.84	37.30
#2C	0.128	18.4	0.48	8.80
#3C	0.199	28.7	0.30	8.50
Total		143.9		$117.60

[1] Values from table 2.

Table 4.--Projected lumber values at particular ages of cherrybark oak under each pattern of development, discounted to the present (1987) at various real rates of interest

Age	Projected lumber value (1987 prices)	Real interest rate 0.02	0.04	0.06	0.08	0.10
-yrs-	dollars					
		Restricted pattern				
30	30.00	16.60	9.20	5.20	3.00	1.70
35	47.00	23.50	11.90	6.10	3.20	1.00
40	90.00	40.80	18.80	8.70	4.10	2.00
45	156.00	64.00	26.70	11.30	4.90	2.10*[1]
50	230.00	85.40	32.30	12.50	4.90	2.00
55	351.00	118.10	40.60	14.30*	5.10*	1.90
60	426.00	129.80	40.50	12.90	4.20	1.40
65	553.00	152.70	43.20	12.50	3.70	1.10
70	707.00	176.80*	45.40*	12.00	3.20	0.90
		Unrestricted pattern				
25	29.00	17.70	10.90	6.70	4.20	2.70
30	47.00	25.90	14.50	8.20	4.70	2.70
35	129.00	64.50	32.70	16.80	8.70	4.60
40	220.00	99.60	45.80	21.40*	10.10*	4.90*
45	266.00	109.10	45.50	19.30	8.30	3.70
50	315.00	117.00	44.30	17.10	6.70	2.70
55	368.00	123.80	42.60	14.90	5.30	2.00
60	507.00	154.50*	48.20*	15.40	5.00	1.70

[1] * = Optimum rotation age.

RESULTS

Analysis 1

At the optimal rotation ages, the restricted and unrestricted patterns of cherrybark oak development appear to represent similar investments at low rates of interest (2 to 5 percent) even though there is a time differential in rotation ages (table 4). The difference between investment potentials of the two patterns widens with increasing interest rates. The shorter rotations of the unrestricted pattern are more favorable at the higher interest rates because the value of the lumber is captured more quickly. The volume growth on the restricted form during the later years is concentrated on the third merchantable log, a log of poor quality (grade 3) and low value. Even though board-foot volumes are increasing rapidly with additional age, the rate-of-value increase of the tree is diminishing. With the unrestricted form, volume is accumulating on the butt log, a log of high quality (grade 1) and high value.

Analysis 2

The optimal harvest age when the prices of all grades of lumber increase at the same real rate can be approximated from table 4 by subtracting the rate of real price change from the real rate of interest. Using this adjusted rate as the new interest rate, one can determine PNW and optimal rotation age from table 4. For example, when PNW is to be evaluated at 6 percent with a real rate of price increase of 2 percent per year, the PNW of the tree is evaluated at the 4-percent real interest rate. With price increases, value will accumulate faster, and may change the optimal rotation age. In the example above, the optimal rotation age for the restricted pattern would increase from 55 to 70 years (table 4).

Table 5 shows the PNW at the optimal rotation age with and without a real price increase of 2 percent for FAS lumber only. While PNW increases at all interest rates, the rotation age only changes in two cases, both in the restricted form. Usually the proportion of the tree that can be utilized as FAS lumber is not enough to change the rotation age. Further, in the two cases of the restricted form where the optimal rotation age did change, the PNW's at other ages were similar, indicating a "flat" curve around the optimal values. At 6-percent real interest the PNW at age 55 was $24.90, only $1.50 below the optimal ($26.40) at age 70. At 10-percent real interest the PNW at age 50 was similar to the optimal value at age 55.

Analysis 3

The results of Analysis 3 are difficult to present in tabular form because of the many interactions that occur among current stand age, stocking rates, the alternative value, the interest rate, and the form of the cherrybark oak. Instead, we illustrate the procedure with an example. We assume a real interest rate of 6 percent, a per-acre stocking of 25 cherrybark oak trees with the unrestricted form, no other trees of value on the land, and a equal to $2,500 per acre. With these parameters fixed, and if the current stand age (c) is 30, then the value of equation 2 will be $4,467, significantly higher than a. In this case one would not harvest the stand and convert to the alternative use until the stand has reached financial maturity. However, if c is equal to 20 years, then the soil expectation value obtained by harvesting at the optimal rotation age, 40 years, and then converting the land to the alternative use, is $2,494. This is slightly less than a. In this case the land should be converted to an alternative use immediately.

DISCUSSION

The optimal rotations of the restricted form of cherrybark oak development were longer, 70 years, at real interest rates of 2 to 5 percent because of increases in lumber quality and quantity. At higher interest rates, the additional value associated with the restricted form was not enough to offset the discounting effects of the interest. Generally, the shorter rotation of the unrestricted form captured value more quickly because more merchantable volume is produced at an earlier age. With certificates of deposit earning a market rate of 8 percent, which includes the rate of inflation, assuming a real interest rate of 4 percent for timber investments is reasonable. Both forms of cherrybark oak have similar PNW's at these rates, but have different optimal rotation lengths.

Rising prices can be expected to lengthen financial maturity and rotation length. Log quality, volume, and tree value increased as rotation length increased. For example, whenever merchantable length increased or the grade of the log improved, the tree became more valuable (tables 1 and 4). With the current demand for oak products, both domestically and abroad, the forecasted price increases for oak lumber (Hoover 1985), and real interest rates of less than 5 percent, the long rotation that produces high quality oaks is optimal.

The validity of the lumber values generated in these analyses is determined by the initial assumptions. The lumber grade value percentages (table 2) were averaged over all diameters and may not be indicative of values at any single diameter. For example, the percentage of grade 1 lumber in an 18-inch, grade 1 log is not the same as the percentage in a 24-inch, grade 1 log. Also, only 16-foot logs were considered in the analyses. Hardwood mills are becoming more specialized and are increasing tree and lumber values by using shorter log lengths to increase the proportion of a log or board that is clear or free of defects.

Table 5.--Present net worth (PNW) at various rates of interest at the optimal rotation age for each form of cherrybark oak development with and without a real price increase of 2-percent for FAS lumber

	Real interest rate				
	0.02	0.04	0.06	0.08	0.10
Restricted pattern					
Without real price increase					
PNW (dollars)	176.80	45.40	14.30	5.10	2.10
Age (years)	70	70	55	55	45
With real price increase					
PNW (dollars)	390.50	100.30	26.40	8.90	3.20
Age (years)	70	70	70	55	55
Unrestricted pattern					
Without real price increase					
PNW (dollars)	154.50	48.20	21.40	10.10	4.90
Age (years)	60	60	40	40	40
With real price increase					
PNW (dollars)	282.10	88.00	31.80	15.10	7.20
Age (years)	60	60	40	40	40

Lumber values rather than stumpage values were used in the analyses because lumber prices were regionally more stable. Stumpage prices were more erratic and reflected local factors such as transportation costs to the processor, terms of harvesting contract, condition of the stand to be harvested (merchantable volume, species composition, stand density, access), supply and demand inferences, and profit margins. Although lumber prices include milling costs, the competitive selling price of lumber was essentially the same throughout the region. To predict the value of a log in the woods, subtract the costs of transporting and converting the log into lumber. These costs will vary locally.

The assessment presented in this paper evaluates only the present net worth of lumber produced by future cherrybark oak trees. The effects of land values, management costs, taxes, intermediate incomes, opportunity costs, and nontimber benefits were not considered because these variables are difficult to predict over an entire rotation. Some yearly costs and revenues, such as incomes from hunting leases and property tax expenditures, could offset each other. All these parameters should be estimated when developing a complete economic analysis.

Nevertheless, the financial comparison presented here appears reasonable in assessing the two patterns of cherrybark oak development. Both patterns are attractive investments at low rates of real interest, even with long rotation lengths of 70 years. However, the shorter rotation of the unrestricted pattern was more favorable at the higher interest rates (6 percent and above). All conclusions drawn from this financial comparison should be interpreted cautiously in accordance with the assumptions.

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RECENT ADVANCES IN THE DEVELOPMENT OF EUCALYPTUS GRANDIS FOR COMMERCIAL PLANTING IN SOUTHERN FLORIDA[1]

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Abstract.--To provide E. grandis with vigor and frost resilience for southern Florida, a 4th-generation seedling seed orchard was developed, and some 360 clones were tested. Stemwood properties of improved trees were studied. Clonal propagation was investigated and utilized to establish commercial plantations[3].

INTRODUCTION

Eucalyptus grandis was planted for pulpwood production on 6,475 ha in southern Florida from the 1960's to the early 1980's. Concurrently, a genetic improvement program conducted by the U. S. Forest Service produced considerable increases in vigor and quality (Geary et al. 1983, Meskimen 1983). Severe freezes not experienced in southern Florida since 1962 (in January 1982, December 1983, and January 1985) identified the necessity for rapid development of frost resilience in E. grandis and provided unique opportunities to select resilient trees. Recent results have continued the previous progress, with emphasis on seed orchard development, wood physical and chemical properties, coppicing, and clonal selection and propagation.

METHODS

GPOP77, a 4th-generation E. grandis genetic base population consisting of 31,725 trees from 529 progenies, was established July 1977 near LaBelle (Meskimen 1983, Rockwood et al. 1986). The southern half of the plantation was harvested in August 1978. GPOP77 was converted to seedling seed orchard GOrch77 in 1986 by retaining a superior tree within each of 1575 selection areas. In the northern half, trees were selected based on 2.5-year seedling performance and subsequent quality criteria at the time of selection. In the southern half, trees were retained based on 64-month coppice volume, form, frost-resilience, and quality (Reddy et al. 1986). Seed were collected from GOrch77 in March 1987 from 24 of the top 50 trees in the southern half. The derived open-pollinated progenies were outplanted in August 1987 in study ORNL-40.

Stemwood sampling was conducted when GPOP77 was rogued in February and March 1986. Representative disks were taken at 1.5 m stem height from trees of 27 progenies: 1 to 10 103-month-old trees/progeny in the northern half of GPOP77, 6 to 11 90-month-old coppice stems/progeny in the southern half. Previous sampling of the 13-month-old trees cut in 1978 (seven/progeny) had been conducted by the U.S. Forest Service using quarter-height stem disks. Routine wood moisture content (MC) and specific gravity (SG) determinations were conducted.

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Additional quarter-height stem sections were obtained from studies ORNL-35 and ORNL-37. Twenty-month-old progenies of E. grandis, E. robusta, E. dunnii, and E. amplifolia in ORNL-35 were provided to TVA, Chemical Engineering, at Muscle Shoals, AL, in March 1987 for hydrolysis analysis including composition of various sugars, lignin, and ash. Samples from one Eucalyptus amplifolia, E. dunnii, E. grandis, and E. robusta in ORNL-35 and one 5.3-year-old ramet of clone 2814 in ORNL-37 were provided to Biodyne Chemicals, Appleton, Wisconsin, for preliminary estimates of tear strength, burst, bulk, breaking length, Kappa number, and yield for the experimental ester pulping process.

Eucalyptus grandis, E. robusta, E. amplifolia, and E. dunnii were planted July 1985 at Belle Glade in ORNL-35 to estimate the effects of genetics, spacing, rotation length, and time of harvest. Until two harvest times were imposed beginning December 1986, the study had six replications of 10-tree row plots including 27 E. grandis progenies and 7 x 10 m plots of E. grandis at 1 x 1 m and 1 x 2 m spacings. Two replications also include 25-tree square plots of five E. grandis progenies and a third spacing of E. grandis at 1 x .5 m. Survival and height were measured semiannually from December 1985 to December 1986. Three replications were harvested in December 1986, and the resulting coppice was monitored in March 1987 and December 1987. A fourth replication was harvested in March 1987 and was assessed in December 1987.

In August 1982, 55 successfully rooted clones, from 100 E. grandis, E. grandis hybrid, and E. saligna Sm. x E. tereticornis Sm. ortets of exceptional tree size, good form, and with minimal damage from the January 1982 freeze (8 hours as low as -11°C), were planted in study ORNL-37 near Palmdale (Meskimen et al. 1987). The 55 clones evaluated in mixed-clone, single-tree plots were measured frequently through 3.8 years. Eighteen clones in single-clone 16-tree blocks replicated four times were last measured at 5.3 years.

Additional clones were derived from an E. grandis pilot test of short-rotation intensive culture established near Palmdale in August 1982 with progenies from eight superior trees. Within the 25 ha test, superior phenotypes were located in December 1986, measured for height, DBH, and frost-resilience, and classified by pedigree as E. grandis, E. grandis x E. robusta, or E. grandis x redgum. Rooted cuttings produced from 232 clones, plus the progenies from GOrch77 and certain genetic checklots, were outplanted in ORNL-40 in August 1987 in the Palmdale-LaBelle area. Within a randomized complete block design with three replications, subplots were used for 1) clonal testing, 2) progeny testing, and 3) genetic gain approximation. Clonal test subplots were subdivided into seven sets, each typically containing 4-tree row plots of 37 new clones and the three top clones determined in ORNL-37. Progeny test subplots consisted of 10-tree row plots of 21 GOrch77 progenies, four progenies from the previous orchard GOrch73, and ramets of the four top clones in ORNL-37. Three GOrch77 progenies were derived from the ortets producing the three top clones. Within-row spacing was 1 m; between-row spacing was 2.85, 2, and 1 m, respectively, in the three replications. Height, DBH, and survival were measured in October 1988.

Preliminary laboratory freeze screening of certain E. grandis clones and progenies and one E. camaldulensis clone was conducted in October 1988. Approximately six-month-old tissue culture plantlets, rooted cuttings, and seedlings were subjected to three freezing regimes in cold chambers used for evaluation of citrus. During a 24-hour period beginning and ending at 4°C, minimal temperatures of -3, -5, and -7°C were held for five hours. Response was evaluated after two weeks.

Additional rooted cuttings of the top clones were employed to establish an 8 ha commercial planting in August 1987. The site was disked repeatedly, and 1120 kg/ha of ground rock phosphate, the usual amendment for successful culture of eucalypts on palmetto prairie (Geary et al. 1983), was broadcast before bedding on 4 m centers. Trees were planted by machine at 2 m spacing.

Regeneration of E. grandis plantlets through tissue culture was evaluated through 1) direct enhancement of shoot multiplication and later initiation of roots and 2) indirectly through callus phase by somatic embryogenesis or organogenesis, i.e., initiation of shoots and/or roots on specified media. In May 1987, clones 2814, 2817, and 2798 provided explant sources for direct enhancement of shoots. Explants were nodal segments from mature branches and from two-month-old sprouts. Sprouts were induced by girdling trees at 1 m above the ground in February 1987. Only healthy looking branches were cut into approximately 10 mm long sections. These sections were surface sterlized and transferred directly to media. Initiation media to elongate axillary shoots contained MS with .5 mg/l benzylaminopurine (BAP) and .05 mg/l of NAA. Axillary shoots were transferred to multiplication media containing MS with different levels of BAP (.2, .6, and 1.0 mg/l), and a combination of .6 mg/l BAP and .02 mg/l of NAA. Elongation of shoots from the multiplication stage was attempted in a media containing high auxin to cytokinin ratio. To investigate rooting of elongated shoots (15-25 mm), 1/4, 1/2, and full strength concentrations of MS media were tried with 1, 2, 3, 4 mg/l concentrations of IBA. In addition, the effect of adding .2 mg/l of BAP to 1.5 and 2 mg/l of IBA was studied. Rooted propagules were transferred to a mist greenhouse for hardening for three weeks and then to a greenhouse.

Indirect micropropagation involved seedlings and floral bud explants. Seeds of E. grandis were surface sterilized and germinated on solid MS medium under aseptic conditions. One-week-old seedlings were then transferred to a callus induction medium. Floral buds collected from

2817, 2814, 2798, and 2786 in ORNL-37 were also surface sterilized and placed on callus induction media. Callus induction for all explants used MS as a basal media with different combinations and concentrations of plant hormones. Seedlings were cultured on a different concentration of the auxin NAA with 1 mg/l of the cytokinin kinetin and 200 mg/l of glutamine. The floral buds collected in July and August 1986 were also tried on a combination of different concentrations of the auxin 2,4-dichlorophenoxyacetic acid (2,4-D) and kinetin. Callus initiation and development in terms of quantity, color, and compactness were monitored. For attempted shoot and embryo induction, callus was transferred to MS with no hormone.

RESULTS AND DISCUSSION

In GPOP77, four generations of selection significantly improved all coppice growth characteristics studied (Reddy et al. 1986). At 64-months of age, differences between 1st-, 2nd-, 3rd-, and 4th-generation trees averaged 206%, 20%, and 55%, respectively, for stem volume. Fourth-generation progenies were also the best for frost resilience and coppice quality. High individual and family heritabilities were observed for all growth traits, suggesting high potential genetic gains through mass selection of the best trees but also higher gains through combined selection of the best trees in the best progenies (Table 1).

Development of GOrch77 (1309 trees in 374 progenies) was a compromise between capturing the maximum genetic gain and maintaining the broadest possible genetic base. As suggested by the gain estimates in Table 1, maximum progress can be made by utilizing the better progenies and best individuals in those progenies. A gain of 90% in coppice volume over the population mean was predicted for a combined selection of the top three trees of the top 100 families. A more selective set of seed trees, e.g., the best 50 trees (presumably from the top 50 progenies) would further increase genetic quality. While the background pollen in GOrch77 would on the average be poorer quality, of course, the potential for commercial seed collection from a limited number of seed trees was demonstrated by Forest Service commercial collections through 1980 (Meskimen 1983). The opportunity for maximizing gain by selective seed collection in GOrch77 will depend on the seed quantities needed. A mature seed orchard tree will produce 2 kg of seed annually yielding 75,000 plantable seedings.

Table 1.--Genetic gains in 64-month coppice volume adjusted for inbreeding for operational seed collection options for GOrch77.

Seed Collection Option	Gain[1] %
All orchard trees	54
30 trees per each of 10 top progenies	41
300 best trees	69
10 trees per each of 30 top progenies	61
200 best trees	80
1 tree per each of 300 top progenies	86
3 trees per each of 100 top progenies	90
Best tree in each of 50 top progenies	179

[1] Compared to GPOP77 average.

Early results from ORNL-40 suggest slight differentials between seedlings from GOrch77 and GOrch73. At 1.25 years in row plots, the 21 GOrch77 progenies were somewhat larger than four GOrch73 progenies but had slightly lower survival (Table 2). Variability among the GOrch77 progenies suggests that the better seed orchard trees can be exploited to maximize genetic gain. Similarly, variability among the four GOrch77 progenies included in pure and mixed block plots suggests gains that can be made by progeny testing GOrch77.

Table 2.--Height, DBH, and survival of *Eucalyptus* entries in ORNL-40 at 1.25 years.

Study Component/ Genetic Entry	No.	Average Height m	 DBH cm	 Survival %
Clonal Test-				
2798,2814, 2817	3	3.2a[1]	3.8a	82a
New Clones	232	2.6b[2]	3.3b[2]	55b[2]
Progeny Test-				
GOrch73 progenies	4	2.1a	2.3a	73a
GOrch77 progenies	21	2.2a[2]	2.5a[2]	66a[2]
Clones	4	2.3a	2.3a	69a
Yield/Competition-				
Progenies	4			
Pure		2.0b	2.1a	70a
Mix		2.2a	2.2a	64a
Clones	4			
Pure		2.2a	2.2a	65a
Mix		2.2a	2.2a	69a

[1] Genetic entry means not sharing the same letter within a study component are significantly different at the 5% level.

[2] Variability among genetic entries significant at the 5% level.

The progenies sampled for stemwood properties are among the best for biomass production. The 13-month-old trees of 22 of these 27 progenies varied in stem wood moisture content and specific gravity (Table 3). The broad ranges among progeny means must be moderated by the limited portion of the data reported here. For SG, however, the range is similar to that obtained with larger samples at older ages. Similar variability in the stemwood properties of older trees and coppice as determined by sampling some eight trees/progeny was evident. Expressed as a percent of the mean, the range among progenies was from 10 to 22% for SG and MC.

Table 3.--Stemwood specific gravity (SG) and moisture content (MC) of seedlings and coppice of 27 progenies in GPOP77.

Characteristic	13-mo. Seedlings	103-mo. Seedlings	90-mo. Coppice
SG (g/cm^3)			
-No. of trees	46	222	222
-Mean	.377	.422	.418
-Progeny range	.341-.418	.396-.464	374-.449
MC (%)			
-No. of trees	45	222	222
-Mean	170	131	135
-Progeny range	146-202	120-144	117-147

Tree age appeared to increase stemwood SG and decrease MC in seedlings (Table 3). The 90-month-old coppice stems were similar in SG and MC to the 103-month-old seedlings, though. In general, 13-month-old seedling SG and MC were not correlated with 103-month-old SG and MC on a progeny mean basis, but young seedling SG was related to 90-month-old coppice SG.

Wood properties of seedling-derived stems and coppice-origin stems were under stronger genetic control when examined on an individual stool basis and when compared at similar ages. SG and MC of 90-month-old coppice stems originating from 46 and 45 stools, respectively, were very similar to the SG and MC of 13-month-old seedlings that had been felled to initiate the coppice. Even though the 103-month-old seedlings were sampled over a large area adjacent to the portion of GPOP77 that had been coppiced, correlations for the same trait were high. Further evidence of genetic control of stemwood SG and MC in E. grandis in Florida is provided by the results of Wang et al. (1984), who predicted gains of up to 25% in these traits.

The eucalypts are suitable as hydrolysis feedstocks (J. Broder, TVA, personal communication). Compositional analysis of four Eucalyptus species by TVA estimated cellulose (glucose) content at 37.5 to 41.6% and hemicellulose constituents (composed mainly of xylose) at 6.4 to 8.1%. In relation to oak, Eucalyptus has higher xylose and lower lignin contents. Applying conversion rates for similar feedstocks to the Eucalyptus sugar compositions, one dry ton of Eucalyptus may be expected to yield 115 pounds of xylose and 400 pounds of glucose, or 36 gallons of ethanol, under the dilute sulfuric acid hydrolysis process. For the concentrated sulfuric acid hydrolysis process with sawdust size particles of wood, one dry ton would yield 130 pounds of xylose and 675 pounds of glucose, or 55 gallons of ethanol. No possible inhibitors to hydrolysis and subsequent fermentation to alcohol were detected. While no problems are anticipated in converting Eucalyptus to ethanol, actual testing is required to define optimum processing conditions and to verify these estimated yields.

Eucalyptus species that can be grown in Florida were found to be equal to native hardwoods for pulping (Franklin 1977), and the properties of young eucalypts appear to be suitable for the ester pulping process. For a 5.3-year-old clone in ORNL-37 and 2.5-year-old trees in ORNL-35, pulping analysis estimated tear at 2.2, burst at 2.75, bulk at 1.25, breaking length at 6.5 mm, kappa number at 33 ml, tensile index at 65.0, and yield at 45% of dry wood. Breaking length was higher than that of species such as aspen. Yield, however, was somewhat low.

Eucalyptus pulp is in high demand by many pulp mills in the United States. When blended with other feedstocks, Eucalyptus pulp is generally acknowledged to improve the speed and operation of pulp machines (W. Heckrodt, personal communication). For some processes and products, Eucalyptus pulp has properties superior to other species (Franklin 1977). For example, Eucalyptus pulp is more absorbent than pulps of our native hardwoods. Eucalyptus fibers are short, stiff, and uniform, retain their bulk throughout the pulping process, and yield two to three times more per ton of pulp than some other woods (McGrath 1987).

Coppicing of E. grandis may be important in commercial plantations. In 6- to 7-year-old plantations, tree size and time of harvest influenced coppice size and survival (Webley et al. 1986). Preharvest height and DBH were positively correlated with coppice size from 4 to 48 months. Coppice survival was as low as 31% with harvests between June and August. In general, failure to coppice was less common than coppice mortality. Mortality was more concentrated in the summer rainy season months with 37% to 68% mortality from June to August. Coppice yields generally declined with summer harvests. Yields of E. robusta were least reduced during August and were relatively stable over a large portion of the 13 harvest months.

Rockwood and Geary (1982) reported that *E. grandis* coppice survival after a December cut averaged 92% after 12 months, was virtually nil after an August cut, and after a February cut reached only 31% on an organic soil.

Compared to other species, *E. grandis* coppiced poorly when grown on organic soils. Before the first coppice rotation was initiated at age 18 months in ORNL-35, species ranking for tree height and DBH was *E. grandis*, *E. robusta*, *E. dunnii*, and *E. amplifolia*. In survival, however, *E. robusta* was first at 75%, *E. grandis* second, *E. amplifolia* third, and *E. dunnii* had only 36% survival. Species' coppicing rates following the December 1986 harvest differed considerably. At 68% overall and with one source having 94% of live trees coppicing, *E. amplifolia* was the only species to coppice adequately. No *E. dunnii* source exceeded 50%, and most *E. grandis* and *E. robusta* progenies failed to coppice. Coppicing after the March 1987 harvest was even less overall. Species ranks changed as *E. robusta* averaged 26%, and *E. amplifolia* had only 2% coppicing. The rates for *E. dunnii* and *E. grandis* were virtually the same as for the December harvest. For *E. grandis*, most progenies again failed to coppice.

For testing the frost-resilience of the clones in ORNL-37, the December 1983 (more than 12 hours, low of -5°C) and January 1985 (down to -6°C over more than 18 hours) freezes represented the coldest conditions that can be expected for southern Florida, providing exposure to both the rarer windborne and more frequent inversion freezes. The 55 clones varied widely in response to the windborne freeze of December 1983, but the norm was severe damage (Meskimen et al. 1987). Survival was excellent before and after the December 1983 freeze. At 2.7 years, clonal differences were significant for all traits, with much of the variability due to the further impact of the inversion freeze of January 1985 (Table 4). The respective assessments to these freezes ranked clones similarly.

Table 4.--Height (H), DBH, survival (S), and stem volume(V) of 55 clones and three best clones through 5.3 years in ORNL-37.

Trait	All Clones		Three Best Clones	
	Mean	Range	Mean	Range
Age 2.7 years-				
H (m)	1.7	0.5-6.0	5.4	4.3-6.0
DBH (cm)	1.6	0.0-6.0	5.2	4.2-6.0
S (%)	90.0	18-100	100.0	-
V (m^3/ha)	2.4	0.0-20.0	16.0	10.7-20.0
Age 3.7 years-				
H (m)	-	-	10.7	10.6-10.9
DBH (cm)	-	-	10.9	9.8-12.1
S (%)	47.0	0-100	100.0	-
Age 5.3 years-				
H (m)	-	-	12.8	11.6-13.8
DBH (cm)	-	-	12.4	11.7-12.8
S (%)	-	-	97.4	96.9-98.4

Gains estimated at 2.7 years suggested that meaningful improvements in frost resilience and tree size can be expected from clonal selection and propagation without testing. However, the additional gains derived from testing of clonal candidates appeared significant. These gains in volume are nearly double estimates developed for seedlings from GOrch77 (Reddy et al. 1986). The size and survival after 3.7 and 5.3 years of the best clones (Table 4) provide the current standard for growth on the extensive "palmetto prairie" lands in southern Florida.

The new cloning candidates selected in 1986-87 at 4.3 years of age were evaluated for phenotypic characteristics, variability in propagation, and early field performance. In comparison to neighboring unselected trees, the candidates were typically much taller and larger in DBH. At 10.9 m in height and 14.0 cm in DBH, the new candidates were similar in size to the same aged best clones in the adjacent ORNL-37. Some candidates were nearly 15 m tall and 20 cm in DBH. Very few candidates were completely undamaged by the 1983 and 1985 freezes. At worst, however, the candidates had sustained minimal stem damage; all regrew magnificently, suggesting very suitable frost-resilience potential.

Because the new candidates were smaller in DBH and shoots were typically collected earlier than the clones included in ORNL-37 in 1982, the average number of cuttings per ortet was less. Percent of ortets with basal sprouts, though, was generally higher, with only seven ortets failing to yield cuttings in 1987. Differences in cuttings/ortet among the three types of ortets were minimal as *E. grandis* and *E. grandis* x redgum ortets averaged 62 cuttings compared to the hybrids with *E. robusta* which averaged 60. Variability levels within the three ortet groups on the other hand were high, typically ranging from about 20 to 160 cuttings per ortet. Rooting percent, similar across ortet groups and comparable to the best clones from ORNL-37, varied greatly within ortet groups. When combined for all new candidates, variation among clones ranged from 0 to 100%. Numerous new candidates exceeded the standard of approximately 80% rooting achieved by the top four clones from ORNL-37. These top four clones were further notable for their rapid growth and firm root structure.

Through 1.25 years, the genetic entries in ORNL-40 varied little (Table 2), while considerable variability between the three reps (planting sites) demonstrated the desirability of excellent site preparation. The site that had very thorough disking and high beds averaged 94% survival with trees 3.0 m tall. Some genetic entries averaged over 7 m on this site, and individual trees were as tall as 7.3 m. The site on which it was impossible to form high beds had 84% survival, but the trees were only 1.4 m in height due to flooding caused by several periods of heavy rainfall. The third site, which had been herbicided to reduce herbaceous vegetation established since bedding in 1982, had only 23% survival with trees averaging .8 m tall.

Surrounding the best site of ORNL-40, the commercial planting of some 11,000 propagules, primarily rooted cuttings of the best clones, further demonstrated the benefit of thorough site preparation as well as the desirability of rainy season planting. Two months after the August planting with ample soil moisture, the portion which had been hand-planted had 94% survival while survival in the machine-planted part averaged 98%. After one year, individual trees were over 6 m tall with excellent stem form and branching. In contrast, the machine-planted portion established in September when moisture was limited had only 80% survival after one month, and after one year these trees were considerably smaller than those planted in August. The cost of site preparation, which included more disking than usual, and planting was approximately $375 per ha. Rotation length at this 1,250 trees/ha planting density is projected to be five to seven years.

In the clonal test component of ORNL-40, clones 2798, 2814, and 2817 displayed good survival and growth. In comparison to these three proven clones, the 232 new cloning candidates were smaller in tree size and inferior for survival overall. Their generally low survival reflected the generally less extensive root systems they developed while in containers. Wide variability among the new candidates, however, suggests that additional clones can be selected for vigor and good survival. In comparison to the height and survival standards of the clonal checks included in each set, 35 clones were better than the checks in height, and 24 clones had higher survival after four months. In row plots, Clones 2798, 2805, 2814, and 2817 were not detectably better than either seed orchard GOrch77 or GOrch73 seedlings. However, differences between clonal and seedling propagules were somewhat detectable in the yield/competition component of ORNL-40 as progenies of four GOrch77 seed trees were smaller in height than clones 2798, 2805, 2814, and 2817 in pure plots.

Our girdling, propagation, and outplanting observations suggest a rigorous schedle is necessary to complete the production cycle during one year under typical climatic conditions (Table 5). Frost risk to developing sprouts limits girdling to no earlier than January 25, with lesser risk if girdling is delayed until early February. With a girdle equal to three chainsaw blade widths and securely through the cambium, no refreshening of the girdle is necessary before collecting shoots. Thus, time spent in the field may be limited to the time necessary for initial girdling and then for harvest only. Cuttings of preferred clones developed roots and were ready for transfer out of the misthouse more quickly. With time under mist of a month, the time from girdling to outplanting could be as little as 170 days for clones with rapid root and top growth. By then, most of the rainy summer planting season (June 15 to August 15) has passed. At the latest, outplanting must occur by the end of August to insure enough growth to convey some hardiness to freezes that usually begin in mid-November.

Table 5.--Proposed clonal propagation schedule for *Eucalyptus grandis* in southern Florida.

Propagation Activity	Starting Date	Ending Date	Days Elapsed
Girdling	January 25	March 1	-
Sticking	April 15	May 15	80
Weaning	May 15	June 15	30
Hardening	June 15	July 15	30
Outplanting	July 15	August 9	30
		Total	170

As conducted in 1987, clonal propagation by rooted cuttings was more expensive than seedling propagation. Girdling a tree was relatively expensive since trees were no denser than 10/ha. Similarly, shoot collection under these conditions was costly. Cutting transport to a nursery was also costly. The nursery operations of sectioning shoots into cuttings, treating cuttings with fungicide, and sticking cuttings in containers were accomplished at between 100 and 120 cuttings/man-hour. Thus, an individual cutting produced by these labor intensive methods had a total investment of 1.03 minutes plus about $.01 in operating costs. At a wage of $6/hour, the estimated cost to produce one cutting was over $.11, with approximately 65% of the cost incurred in the sticking phase.

Numerous options are available for expanding the number of cloning candidates. As demonstrated by the considerable commitment to locate and evaluate candidates for ORNL-37, the likelihood of finding successful clones within available germplasm in Florida can be improved by using 2nd-, 3rd-, or 4th-generation trees developed from introductions into Florida (Meskimen et al. 1987). The success rate for such trees in GPOP77 was almost four times greater than for new introductions. However, a sizable investment was necessary to develop 2nd- or more advanced generation populations from introductions of provenances into Florida (Rockwood et al. 1986). GOrch77 still has numerous candidates for clonal propagation and testing.

The 1987 cloning candidates represent the advantage of searching advanced-generation populations. These progenies of superior seed orchard trees yielded a proportion of propagated candidates higher than that developed from GPOP77 (Table 6). This would be expected as these progenies on the average were better than the average in GPOP77. Only the completion of clonal testing in ORNL-40, with the identification of clones equalling or surpassing the three best in ORNL-37, can establish the final "keep rate".

Table 6.--Culling rates for developing frost-resilient *E. grandis* clones in GPOP77, commercial plantings, and selected progenies.

	GPOP77		Commercial Plantings	Progenies	
	Number	%	Number	Number	%
Trees Planted	23,100	-	8,800,000	82,650	-
Cloning Candidates	8	.251	22,095	241	.292
Clones Propagated	32	.139	12,190	232	.281
Clones Qualified	3	.013	1,143	-	-

A further substantial resource of adapted eucalypts, the commercial plantations in the Palmdale area provide excellent opportunities for immediate expansion of clonal candidates. Younger plantations developed from seed collected from selected parent trees in GOrch73, i.e., plantations established after 1976, constitute more likely sources of superior trees. Consequently, the GPOP77 rates given above bracket the potential for rapidly developing more clones. Under these assumptions, over 1,000 clones (Table 6) may be secured, but only with a major commitment of time and personnel, estimated at some three man-days per candidate when initial selection, propagation, and testing are considered (Meskimen et al. 1987). In spite of these commitments, clonal propagation remains the only short-term alternative for insuring *E. grandis* plantation survival against otherwise catatrophic freezes.

Other species may offer more frost resilience, even resistance. Four E. *camaldulensis* tissue culture derived clones performed well in central and southern Florida during the 1983 and 1985 freezes (Rockwood and DeValerio 1986). Additional *E. camaldulensis* and *E. tereticornis* trees that withstood the December 1983 freeze were interplanted in July 1985 in the current orchard of *E. camaldulensis*/*E. tereticornis*.

Comparative species differences were noted in laboratory freeze screening. The *E. camaldulensis* clone displayed superior resilience at all three minimum temperatures and in fact was the only genotype to survive at -7°C. All *E. grandis* entries survived at -3°C, while several withstood the -5°C regime. In general, variability among the *E. grandis* entries parallelled observed field resilience. Notably, some seedlings from the more resilient clones were hardier than ramets from these same ortets. Laboratory screening of *Eucalyptus* for freeze resilience appears feasible.

Direct enforcement of numerous shoots/buds was successfully achieved with sprouts/explants on MS supplemented with 0.5 mg/l of cytokinin BAP and 0.05 of auxin NAA. On the other hand, 100% contamination was observed on the lignified branches. Similar results were also observed with mature explants such as shoots and lignotubers. This suggests that newly formed sprouts not exposed to field conditions are more suitable explants.

Multiplication of axillary shoots from sprout nodal segments was best achieved on .6 mg/l of BAP. More BAP caused yellowishness of the shoots and reduction of their number. Also addition of NAA produced fewer shoots. It was also observed that subculture every 3-4 weeks of shoot clumps produced healthier and more shoots compared to single shoot subculture. This has practical implication since its easier to subculture clumps rather than single shoots.

Elongation of shoots was successfully achieved on the combination of 2.5-4 mg/l of IBA and 1 mg/l of the cytokinin zeatin. Reduction of zeatin to .5 mg/l resulted in production of much callus. Further reduction resulted in root formation. Also high light intensity produced stronger shoots. Shoots reached 15-25 mm length in three weeks and leaves tended to expand under such conditions. A clump of approximately 5x5 mm from the multiplication stage produced an average of about 30 elongated shoots.

Rooting of elongated shoots depended on the physiological state of shoots, type of media, and environmental conditions. Healthy shoots with 2-4 leaves had better rooting with higher percentage. In addition, reduction of the mineral nutrient to 1/4 MS improved rooting quality and reduced callus production. However, concentrations of plant hormones in the media were found to the most critical factors in the rooting process. Rooting was best with 2 mg/l of IBA.

More IBA produced more callus and more hairy roots. Addition of only .2 mg/l of BAP resulted in complete inhibition of root initiation. Also incubation of the culture under dark conditions for the first 5-6 days in the rooting media improved the rooting quality and percentage. Rooted propagules were successfully hardened in a mist-greenhouse and then in a greenhouse with survival of 95% and 100%, respectively.

Hartman's Plants Inc. used direct micropropagation for the commercial multiplication of certain E. grandis and E. camaldulensis clones in 1988 (Table 7). Initial propagation efforts in Summer 1986 with branches were generally unsuccessful due to the production of phenolic compounds by the explant material. Follow-up propagation in March 1987 involving different ramets of clones 2798, 2814, 2817, 2805 and others using modified propagation techniques was successful. Approximately 40,000 propagules were produced on a MS-based media with 0 to 0.2 ppm BA and 1 to 10 ppm IAA. Once rooted, the propagules were grown in a greenhouse for 12 weeks, then moved to shadehouses for 12 weeks for hardening.

Table 7.--Performance of 11 Eucalyptus clones in micropropagation at Hartman's Plants Inc.

Clone	No. of Ramets[1]	Relative Rate of	
		Multiplication[2] (4 weeks)	Elongation[2] (2 weeks)
E. grandis-			
29	1	4	3
37	1	4	3
45	1	4	3
2786	2	3	5
2787	2	3	5
2788	2	3	5
2798	1+	3	2
2805	3	4	1
2814	3+	1	4
2817	2+	2	2
E. camaldulensis-			
174	1	4	2

[1] Number of ramets; +=mixture of ramets supplied in addition to individual ramets.

[2] 1=Best, 5=Worst.

While these four clones adapted readily to culture in 1987, differences were observed in several aspects of propagation. Generally, tissue maturation appeared unimportant to successful capture of the ramet by tissue culture, as buds from juvenile shoots, mature shoots and coppice material gave similar results within each clone. Although each of the primary clones gave adequate multiplication rates, there were clear differences between the clones with respect to their response to the tissue culture environment. Relative sensitivity to cytokinin was the largest difference noted with 2814, 2817, 2798 and 2805 being the order of decreasing sensitivity. Some of the minor clones and 2798 had a tendency to produce callus on the apical meristem in conjunction with a vascular necrosis that killed small clumps of shoots. This problem was not resolved.

Once the clones were established in tissue culture, they were subcultured on increased cytokinin-containing media on a four-week cycle. Once adequate numbers of shoots had been initiated, the cultures were transferred to an elongation media and then to a rooting media. Some 30,000 rooted shoots were planted in the greenhouse from week 10 to week 14. On week 26, 10,000 plants were transferred to Herren Nursery where they were raised in Ray Leach "Stubby" containers for an additional eight to ten weeks before out-planting during the late summer.

Experience acquired will guide micropropagation efforts of these and other clones in the future. Further study of levels and kinds of growth regulators in the production and rooting of propagules, of effect of physical environment on propagules, of effect of previous phases of production on later phases, and of methods for establishing propagules ex vitro is needed.

For indirect production of plantlets, formation of callus was observed for one-week-old seedlings after three to four weeks on the callus induction media. Highly morphogenic callus, deep red, compact and superfically granulated, was observed on the combination of 4 mg/l of NAA, 1 mg/l of kinetin, 200 mg/l of glutamine, and MS as basal media. Upon transfer of this callus to MS with no hormone, smooth, red pigmented, and round structures started to form, which later gave rise to shoots, roots and whole plantlets in two to three weeks. While such callus was described as embryogenic, verification proof must come through cytological studies.

After three weeks in culture, floral buds produced different amounts and kinds of callus. Compactness increased with increasing auxin concentration. Kinetin also increased compactness of the callus. The 2.0 mg/l of 2,4-D produced the largest amount of callus. No organization or root formation was observed. When calli were transferred to media with no or low 2,4-D, no differentiation was observed, and the calli began to degenerate.

Collectively, these genetic, silvicultural, and propagation developments hold promise for producing Eucalyptus in Florida to meet a growing demand for Eucalyptus pulp in the U. S. (McGrath 1987). If U. S. pulp mills continue to increase hardwood in their furnishes and the price of imported bleached Eucalyptus pulp rises ($580/delivered metric ton in mid-1987) due to a demand that has been increasing 19% annually, domestically produced Eucalyptus will become competitive.

Should further analyses support the use of Florida-grown eucalypts for the ester process, the current constraint of long distance between production site and mill location could be addressed by constructing new mills in central or southern Florida. Presently, southern Florida eucalypt plantations are some 200 miles from the nearest pulp mill. Ester pulp mills, because they have relatively low environmental demands in that they produce few emissions and consume less water, may be compatible with construction regulations in Florida. Under present economic and production scenarios, E. grandis can be profitably grown in short rotations for energy wood (Rockwood and Dippon 1989).

CONCLUSIONS

GOrch77 can provide commercial seed production of vigorous, somewhat frost-resilient, good coppicing E. grandis. Exceptional individuals in GOrch77 are also candidates for clonal propagation.

Modest genetic variability was observed in SG and MC of E. grandis stemwood of different ages and origins. SG of young trees is less than that of older trees, while MC is higher. A similar comparison may apply to fast-growing trees on muck soils compared to trees growing on "palmetto prairie." Coppice stems and seedling stems of similar ages appear to have similar properties. Eucalyptus appears suitable for the production of ethanol by fermentation following either dilute or concentrated sulfuric acid hydrolysis pretreatment. Eucalyptus species also seem acceptable for the ester pulping process.

Coppice survival, growth, and productivity, of Eucalyptus species may be influenced by genetics, spacing, site, time of harvest, and age of stand. E. grandis was highly sensitive to time of harvest, notably during the summer, suggesting that summer harvests (June to September) should be avoided.

Clones identified by testing will greatly reduce the freeze risks associated with E. grandis culture in southern Florida. Three clones are now recommended for commercial propagation. From the candidates selected and outplanted in 1987, additional clones with desirable features may be anticipated. Commercial plantations, the current E. grandis seed orchard, and other orchard situations provide longer-term options for developing clonal candidates. Consideration of E. camaldulensis seems warranted as a means of achieving greater freeze resilience.

Propagation options studied included rooted cutting and tissue culture techniques. Basal coppice shoots from mature trees which have shown superior traits are good sources of materials for vegetative propagation. Large numbers of rooted cuttings can be produced from selected clones for outplanting in one year. Tissue culture was successful for selected E. grandis and E. camaldulensis under certain conditions. Propagation of certain clones through direct enhancement of shoots from juvenile sprouts was very successful with a very high rate of multiplication. Also, propagation through callus phase of material from young seedlings was successful.

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DEVELOPMENT OF CHERRYBARK OAK IN AN UNEVEN-AGED STAND IN WEST TENNESSEE[1]

James M. Guldin and Tony Parks[2]

ABSTRACT. Three 0.2-acre plots, containing cherrybark oak and other species from 2" to 28" dbh, were purposively sampled within a five-acre block of a 1200-acre stand managed for 80 years using uneven-aged silviculture. All trees on each plot were mapped, identified by species, and measured to include dbh, total height, and crown dimensions; all trees were cut at 0.5 foot, and dissected at 3-foot increments to determine tree age at each given height. Cherrybark oaks originating between 41 and 50 years ago were found on each 0.2-acre plot; cherrybark oaks originating between 31 and 40 years ago were found on two of the three plots. Both age classes showed evidence of not only interspecific but also intraspecific stratification of cherrybark oak beneath older age classes.

Given the normal harvest of trees 36" dbh and larger from this uneven-aged stand, the nominal single-tree selection functions ecologically as group selection, in which the harvest of a single tree promotes the release of a small even-aged cohort of established advance regeneration in open conditions. These results suggest that cherrybark oak can be managed using uneven-aged silviculture. Hypotheses whereby stand-level even-aged conditions are required for successful regeneration of cherrybark oak may thus be subject to reconsideration. [3]

INTRODUCTION

Over the past two decades, a decline in representation of cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) in newly-regenerated mixed-species bottomland hardwood forests through the Mississippi River valley has been observed. The developmental dynamics of cherrybark oak have thus received much attention in recent years (Clatterbuck and Hodges 1988; Hodges and Janzen 1987; Janzen and Hodges 1987, 1985; Aust 1985; Clatterbuck et al. 1985; Aust et al. 1985). These studies build upon other work describing the ecological dynamics of regeneration establishment, and the subsequent development of the sapling and pole classes of red oak in stands in which it is a major component (Oliver 1978; Loftis 1983, 1985).

All of these studies emphasize red oak development in even-aged stands or, more specifically, even-aged generational events that undergo differentiation during the stem exclusion stage (Oliver 1981). As a result, methods are proposed for management of oak that recommend the shelterwood method or perhaps even clearcutting, coupled with midstory removal treatments that promote the development of vigorous advance regeneration of oak that might be subsequently released in conjunction with the shelterwood removal cut or the clearcut. This release will eventually result in the dominance of red oak through characteristic patterns of crown stratification (Clatterbuck and Hodges 1988; Oliver 1978).

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A critical question is whether stand-level even-aged systems are essential for red oak to become established, undergo release, and express dominance through stratification. Even-aged methods such as clearcutting and shelterwood were neither recommended nor practiced in bottomland hardwoods until three decades ago. In the Mississippi Valley, the origin of most of the stands in which cherrybark oak is abundant was through 'selective cutting' that more closely approximated uneven-aged rather than even-aged forestry. In those instances where uneven-aged silviculture was in reality a high-grading that released tolerant undesirables of the same age as the harvested trees, vigorous silvicultural condemnation is in order.

However, one can hypothesize that uneven-aged methods using group selection, coupled with control of the undesirable midstory and understory, will promote ecological conditions in the group openings that might favor the establishment and release of desirable oak in a manner similar to that in even-aged stands. Empirical support for this hypothesis exists in uneven-aged stands managed by Anderson-Tully Company, on the eastern bank of the Mississippi River in Tennessee as well as on the upland loessial deposits east of the Mississippi River bottomlands in Mississippi, where cherrybark oak stems of widely varying size classes are commonly intermingled throughout the stand.

The objective of this study was to determine patterns of stratification of different size classes of cherrybark oak in an uneven-aged mixed-species bottomland hardwood stand in west Tennessee.

Stand History

The Polsdorfer Tract, a 1200-acre tract located north of Fort Pillow State Park in Lauderdale County, Tennessee, was purchased by Anderson-Tully Company in 1902. It was part of the Ohio River drainage until the shift of the Mississippi River to its present channel some 1600 years ago. The site has a more acid pH and a greater percentage of silt than the soils in other areas of the Mississippi River overflow lands due to colluvial deposition from adjacent silty uplands. This is reflected in the species composition of the area, and in the improved conditions for natural regeneration of red oaks. The area is submerged for several weeks during spring overflows of the Mississippi River, which occur in this area about once every four years.

A natural catastrophe of undetermined origin occurred on this site in the late 18th century, at which time residual sweetgum (Liquidambar styraciflua L.) and cherrybark oak trees re-seeded the area. The regeneration was probably a thick stand of sweetgum, interspersed with cherrybark oak. The oak gradually overtopped the gum, such that at age 80, the stem count was on the order of 80% red oak and only 20% gum.

Prior to 1902, the previous owners of the tract, St. Louis Box Company and the Polsdorfer Company, cut only large scattered individual trees on this tract. The old-growth canopy was not greatly disturbed. Anderson-Tully cut mostly scattered cottonwood (Populus deltoides Bartr. var. deltoides) and veneer gum logs before World War I. The shift in company production from wooden boxes to hardwood lumber at the turn of the century did not entail a shift in harvesting strategy; after the war, large scattered red oak and gum veneer logs were still cut, based on species and size as judged by the loggers.

During the 1930s, large herds of cattle were moved from the dust bowl of the Southwest to eastern timberlands for survival. This area had a large cattle population for several years during this time, and developed an understory of tolerant species, mostly hickory (Carya spp.). As the seedlings were grazed by the starving cattle, a dense bed of hickory rootstocks developed. When the cattle were removed in the late 1930s, the rootstocks quickly put out tops several feet tall the first year. In 1938 Anderson-Tully began marking the timber to be cut using single tree selection; however, the company did very little cutting in this area between 1930 and 1950. That which was done was for large trees, scattered about the tract.

In 1950, this area supported a heavy stand of cherrybark oak and red gum. There was virtually no mid-story, and the understory was full of hickory and box elder (Acer negundo L.). The average volume per acre was estimated at 7500 bf[1] of cherrybark and other red oaks, mostly Nuttall (Quercus nuttallii Palmer) and willow (Quercus phellos L.) oak, plus an additional 2200 bf of red gum. About 30% of the trees had 24 inches of red heart, and of this about 30% was figured. Between 1950 and 1956, 2250 bf per acre was removed from the stand. Between 1972 and 1980, the area was again harvested, with a removal of only 2118 bf per acre; most of this was gum, leaving mostly cherrybark oak in the overstory. Many log-sized intermediate stems were also cut, including hickory, elm (Ulmus spp.), hackberry (Celtis occidentalis L.), box elder, and silver maple (Acer saccharinum L.) and green ash (Fraxinus pennsylvanica Marsh.) in the lower areas. Between 1985 and 1987, approximately 3400 bf per acre was harvested, of which 63% was either cherrybark or other red oak. The standing volume in 1986 was 7380 board feet per acre, of which 68% was red oak.

METHODS

In the summer of 1988, a stem-analysis study was implemented to determine the age structure of this stand. Three 0.2-acre plots, lying within a 5-acre block of the stand, were purposively located and measured. Each plot contained at least three apparent size classes of cherrybark oak. All trees above 2.0" on the plot were measured for dbh, species, total height, height of the live crown, and crown radii along four cardinal directions. Each stem was mapped. Following the measurement, stems were cut at 0.5 foot; cross-sections were taken at 3', 4.5', 6', and every 3' thereafter along the main stem to the terminal leader; these were numbered as to tree and height, and rings at each section were counted in the lab. Height-age growth patterns were determined for five-year increments based on linear interpolation of ages at each section.

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[1] All volumes in this paper are expressed using the Doyle rule.

RESULTS

Diameter distribution

The diameter distribution of this midstory component is a normal or bell-shaped curve, particularly prominent in the cherrybark oak midstory component (Figure 1). The curve of all species appears to be skewed toward the smaller diameter classes, suggesting a certain measure of oppressed growth in those classes compared to the development of the 12" to 18" classes.

Age structure

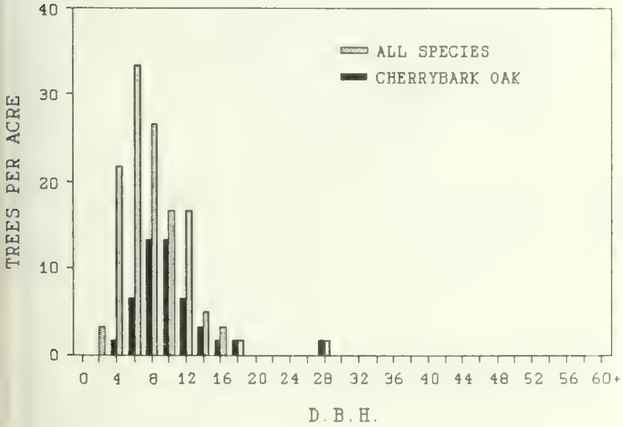
The plot data reveal at least two distinct age classes - the relict stand, represented by the 120-year old trees in the 28" class, and a vigorously-differentiating midstory component (Figure 2). However, the purposive sample did not include the largest diameter class of cherrybark and white oak (Quercus alba L.), which ranged from 48" to 60" dbh. Adjacent to the sample plots in the five-acre area, stumps larger than 50" in diameter from recently-harvested cherrybark oak and white oak were aged. The cherrybark oak stumps ranged in age from 100 to 120; the white oak stumps were over 250 years old. In addition, a even-aged cohort of cherrybark oak saplings, not included in the sample plots, was also observed in the five-acre block; these trees were between four and six inches in diameter, and ages determined by cores taken at dbh ranged from 23 to 28. Thus, based on evidence from plot data and from observations within the five-acre block, we postulate the existence of no fewer than five age classes of cherrybark oak in this stand.

The major midstory component appears to have originated roughly as a single generational event, between 41 and 50 years ago. This would have been from operations between 1938 and 1948, during which time the company records indicate little cutting. The most prominent event at that time may have been the withdrawal of grazing pressure. It is conceivable that the dense stand of seedlings described at the time may have contained a minor cherrybark oak component, which subsequently stratified above its associated species according to patterns in the literature (Clatterbuck and Hodges 1988), though occurring beneath a scattered canopy of larger and older trees.

However, a small but notable cherrybark oak component became established in the 1950s, though the proportional representation in this age class is weighted toward other more tolerant species. The younger age classes were recruited and/or released during the single-tree selection harvests occurring later than the harvests by which the 41- to 50-year age class was released. However, these cuts during the 1950s also released a large component of tolerant undesirable species, such as mockernut hickory (Carya tomentosa Nutt.) and other hickories, winged and slippery elm (Ulmus alata Michx. and U. rubra Muhl.), silver maple, and box elder.

Height growth

The height growth pattern of the largest cherrybark oak in the first two sample plots, along with the height growth pattern of their five nearest neighbors, are presented in Figures 3 and 4. On the first plot (Figure 3), the tolerant understory is both smaller and younger



igure 1.--DBH distribution for cherrybark oak and all species, A-T Polsdorfer Tract; data from three 0.2-ac stands dissected by stem analysis.

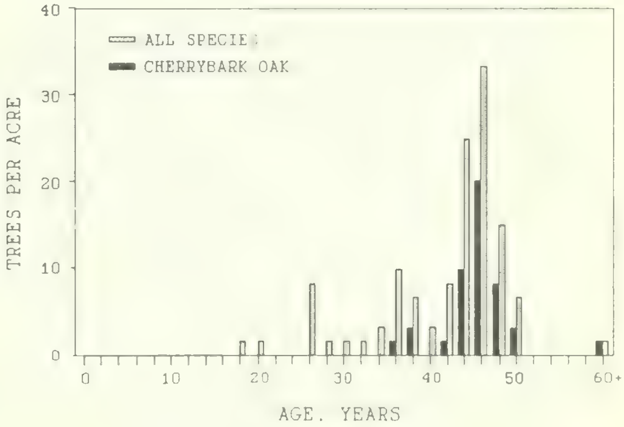


Figure 2.--Age distribution for cherrybark oak and all species, A-T Polsdorfer Tract; data from three 0.2-ac stands dissected for stem analysis.

than the oak component. There is little doubt that single-tree selection promotes a release of tolerant species. The establishment of cherrybark oak in this understory is not likely to be uniformly successful or predictable. The rapid height growth of cherrybark oak in association with water oak (Quercus nigra L.) on this plot is consistent with unrestricted patterns reported by Clatterbuck and Hodges (1988) though at lower heights, which may be due to the suppressing nature of the overstory.

On the second plot (Figure 4), the mixed cherrybark and water oak component in the 41- to 50-year age class has developed as a dense clump. The cherrybark oak that assumed dominance at age 45 appears to be the future growing stock of the stand, as judged by its larger dbh and favorable crown position. However, of equal interest in this graph is the establishment and subsequent development of a desirable component of cherrybark oak and green ash in the 31- to 40-year age class. These trees exhibit a mid-canopy stratification occurring not only beneath the canopy of not only its decade-older associates but also beneath both the 100-120-year age class and the 250-year age class. The presence of these trees illustrates that single-tree selection can promote developmental dynamics of desirable species in an uneven-aged condition.

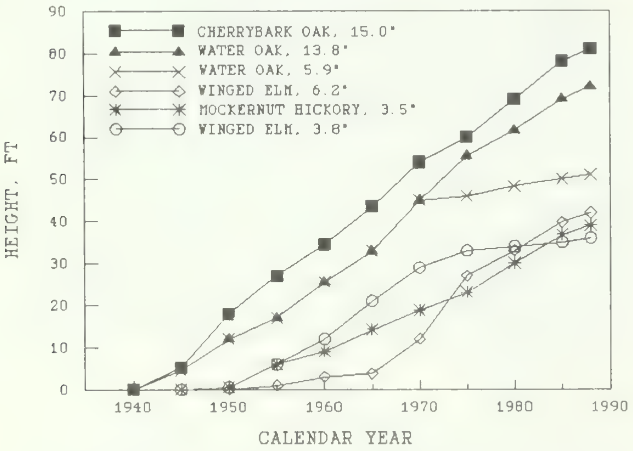


Figure 3.--Stem analysis of largest cherrybark oak and its five nearest neighbors, plot 1 in this study.

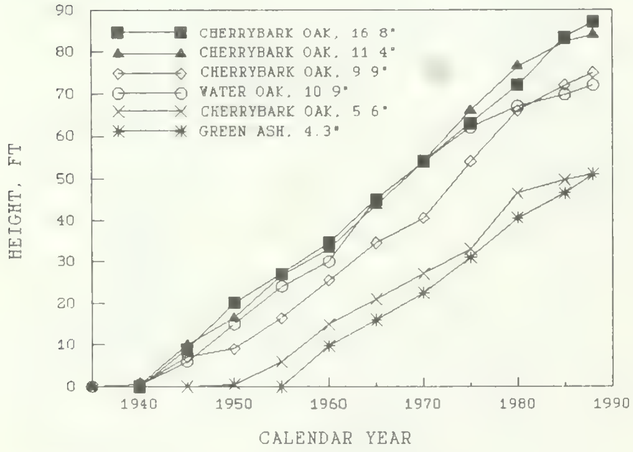


Figure 4.--Stem analysis of the largest cherrybark oak and its five nearest neighbors, plot 2 of this study.

Intraspecific height-growth patterns are presented in Figure 5, in which the height growth pattern of the largest cherrybark oak of plot 3 is compared with its nearest oak associates. One cherrybark oak on this plot has stratified above a larger Nuttall oak; the remaining stems, of both the 31- to 40-year and 41- to 50-year age classes, are still in a differentiating phase. However, the trees of this plot are about 20 feet shorter than trees of equal age on plots 1 and 2. The height growth pattern suggests that these trees were suppressed by a larger overstory tree until its removal in the early 1970s, at which time a vigorous development and stratification was able to commence. Since 1970 and especially over the last 13 years, the rate of height growth of the tallest cherrybark oak on plot 3 has been greater than that of any other cherrybark oak on the analyzed plots.

CONCLUSIONS

The absence of total overstory removal coupled with the development of cherrybark oak in the 41-year to 50-year age class suggests that cherrybark oak can not only tolerate but also develop vigorously beneath some degree of partial shade. Evidence also suggests that the tree can respond to release, such as after 30 years of suppression by a high overstory. However, the representation of cherrybark oak in this age class indicates the action of some unknown series of deliberate or fortuitous silvicultural events that established an

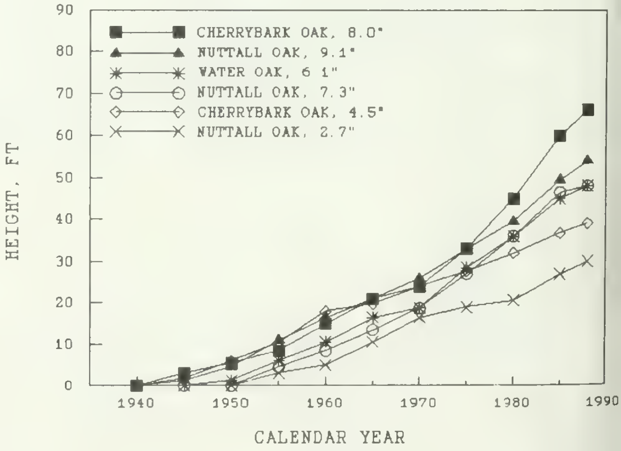


Figure 5.--Stem analysis of the largest cherrybark oak and its five nearest oak neighbors, plot 3 of this study.

unquantified but retrospectively adequate stocking of advance growth of cherrybark oak, which was then released with subsequent selection harvesting.

An alternate hypothesis is that seedling regeneration of cherrybark oak can be obtained and released using uneven-aged silviculture. Under this hypothesis, group selection promotes openings in the canopy under which regeneration can become established at the time of harvest. Empirical observations throughout the 1200-acre stand supports this hypothesis, and the authors are engaged in further research to test the veracity of these observations.

The limited evidence generated by the plot sample suggests that cherrybark oak has not been a major component of the understory in years since the development of the 41- to 50-year age class. However, stem analysis indicates that if a cherrybark oak stem can be established in the understory, such as in the 31- to 40-year age class that was released during a single-tree or group-selection harvest, it will respond to release and develop in a vigorous manner. Single-tree selection as practiced by Anderson-Tully, of stems 48" dbh and larger, probably creates a canopy gap that promotes microclimatic ecological conditions similar to those found in group-selection openings of smaller sawtimber.

One conclusion that is consistent with these observations is that the absence of cherrybark oak is due not to a disruption of developmental dynamics of advance growth and sapling classes, but is rather due to the failure to obtain sufficient advance growth in the first place. By this logic, it might be premature to dismiss uneven-aged silviculture of cherrybark oak because of unfavorable developmental dynamics in the small established sapling classes. Rather, the lack of advance growth initially in uneven-aged stands may, as in even-aged stands, play a role in reductions in cherrybark oak stocking. Particularly in the group selection method, cherrybark oak advance regeneration might be encouraged in the same manner as has been hypothesized in even-aged stands, such as through silvicultural treatments that eliminate the undesirable midstory component.

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Vegetation Management

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LOBLOLLY PINE AND HERBACEOUS PLANT RESPONSE TO AGRICULTURAL HERBICIDES[1/]

By James D. Haywood[2/]

Abstract.--Loblolly pine seedling survival, damage, and herbaceous plant control for the first growing season in the field are reported for herbicide trials in 1979, 1980, and 1987. Among herbicides used in soybean culture, Basagran, Lasso, Lexone 4L, and Surflan A.S. did not damage loblolly pine when sprayed over unshielded newly planted seedlings, but only Surflan A.S. controlled the herbaceous vegetation. Treatments by herbicides not used in soybean culture, Atrazine 80W, Bladex 4L, Atrazine 80W+Bladex 4L, and Goal 2E, did not damage pine seedlings and were effective for herbaceous plant control. The change in loblolly pine diameter and height growth on plots treated with an Oust+Velpar L treatment was related to date of application. Oust and Velpar L were the best herbicides tested when both pine seedling tolerance and herbaceous plant control were considered.

INTRODUCTION

Many acres of marginal agricultural lands are being converted from traditional row crops to loblolly pine (Pinus taeda L.) under government incentive programs, such as the Conservation Reserve Program, and because of low commodity prices.[3/] Since millions of acres of old fields have been successfully converted from row crops to pines in the past, this latest effort proceeded rapidly without first determining if there might be any potential problems with pine establishment. A serious problem has now developed in former soybean fields: poor survival of planted loblolly pine seedlings.

The Georgia Forestry Commission and Auburn University, with assistance from the Southern Forest Experiment Station (USDA Forest Service), have initiated a research project to address this problem.[3/] One part of the project concerns injury of pine seedlings by Oust (sulfometuron methyl) in old soybean fields where soil pH is more basic than in forest soils. Another part of the project concerns the build-up of residual herbicide(s) in the soil after several soybean rotations.

In 1979 and 1980, studies were conducted using selected herbicides to determine their value as herbaceous plant control agents for future long-term research studies with loblolly pine. Several herbicides labeled for use in herbaceous plant control for both soybean fields and tree crops were tested. In 1987, an Oust+Velpar L combination (the water dispersible liquid formulation of hexazinone) was tested with seven different dates of application. The results obtained from these studies are applicable to the reforestration work on former agricultural lands.

METHODS

Study Establishment

All field tests were conducted on a Beauregard silt loam (Plinthaquic Paleudult, fine-silty, siliceous, thermic) in Rapides Parish, Louisiana. Sites were harrowed twice to disrupt grasses and forbs.

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[3/] Mitchell, R. J.; Gjerstad, D. H.; Kelly, W. 1987. Failure of pine seedlings on abandoned soybean fields-- A herbicide, nematode or mycorrhizal problem? Georgia Forestry Commission Research Project Proposal, Georgia Forestry Commission, Macon, GA. 4 p.

For the 1979 and 1980 field tests, two 1-0, graded, bare-root loblolly pine seedlings were planted by hand 1 foot apart on 0.45 milacre plots. Seedlings were planted in January of 1979 or 1980. Dead or injured seedlings were replaced in February and March in the 1979 test. The plots were in a randomized complete block design with 6 blocks for the 1979 test and 10 blocks for the 1980 test. Blocks were established because of differences in slope and vegetative cover after harrowing. Each block had 13 plots (2 untreated controls) in the 1979 test and 7 plots in the 1980 test (1 untreated control).

For the 1987 field test, seven 0.07-acre plots were established in a nonrandomized, unreplicated ranking based on treatment date. Each plot contained eighty 14-week-old container grown loblolly pine seedlings planted by hand at a 6- by 6-foot spacing on March 4, 1987. Twenty pine seedlings per plot were used for measurement trees. All plots were fertilized at planting with triple superphosphate (P_2O_5) at an average rate of 143 lb P/acre.

Treatments

For the 1979 and 1980 field tests, the herbicides were sprayed uniformly over the tops of the pine seedlings in a 35 gal/acre water solution. Application was made with a hand-pump sprayer, and a plastic-lined cylinder was used to delineate the plot perimeter and to prevent drift. Herbicides were applied on the dates and at the concentrations shown in table 1.

For the 1987 test, the Oust+Velpar L herbicide treatment was sprayed uniformly with a backpack hand-pump sprayer over the tops of the pine seedlings in a 60 gal/acre water solution. One of the herbicide applications was made to each plot on the dates shown in table 2. The herbicide concentrations were 0.4 lb active ingredient (ai) of Oust/acre and 1.0 lb ai of Velpar L per acre. On the March 8 application, the herbicides were applied before the herbaceous vegetation emerged. The application on April 8 was to both pre-emergent to early post-emergent vegetation. On May 6, the herbicides were applied to early post-emergent vegetation. The soil was moist on the surface. The remainder of the applications were to actively growing vegetation, and the bare soil was moist on the surface, with the exception of the September 2 application in which the bare soil was dry on the surface but moist beneath.

Pine Damage

Pine seedlings were examined for damage through June 1980 in the 1979 test and through May 1981 in the 1980 field test. Damage was classified as follows:

Slight damage: 0 to 15 percent of the needles are chlorotic or burned,

Moderate damage: 16 to 50 percent of the needles are chlorotic or burned, and

Severe damage: 51 percent or more of the needles are chlorotic or burned, terminal leaders may have died back, or seedling may be dead.

For the 1987 test, loblolly pine groundline diameter was measured in March 1987 and February 1988. Seedling height was measured through March 1988. A measure of volume response to date of treatment, groundline diameter squared, then multiplied by height, was calculated for each surviving seedling, first using the March 1987 groundline diameter and height data and then the February 1988 groundline diameter and March 1988 height data. All measurements and calculations were in centimeters.

Herbaceous Vegetation

In the 1979 test, herbaceous plants, comprising at least 2 percent of the ground cover on the untreated controls, were panicums (Dichanthelium spp. and Panicum spp.), arrowfeather threeawn (Aristida purpurascens Poir.), bluestems (Andropogon spp.), paspalums (Paspalum spp.), crabgrass (Digitaria spp.), swamp sunflower (Helianthus angustifolius L.), and poor-joe (Diodia teres Walt.).

For the 1980 test, herbaceous plants present on at least 60 percent of the untreated controls were panicums, swamp sunflower, gayfeathers (Liatris spp.), poor-joe, and hypericum (Hypericum spp.).

Herbaceous plant control following herbicide treatment was estimated through August in both the 1979 and 1980 tests as follows:

Poor: 0 to 30 percent of the plot surface not shaded,

Fair: 31 to 60 percent of the plot surface not shaded,

Good: 61 to 97 percent of the plot surface not shaded, and

Excellent: 98 to 100 percent of the plot surface not shaded.

For the 1987 test, percentage of plot surface bare of vegetation around each seedling was estimated to the nearest percent through October 1987. The herbaceous vegetation was not systematically inventoried, but it was similar to the other two tests.

Data Analysis

For all field tests, data comparisons were not based on statistical analyses because of the small number of sample pines in the 1979 and 1980 field tests, and the 1987 field test was not replicated.

RESULTS

Loblolly Pine

In the 1979 field test, considering all treatments, 29 percent of the loblolly pine seedlings sustained severe damage, mainly because all seedlings receiving the two Velpar (hexazinone in a water soluable powder formulation) treatments died (table 1). Pine damage by the soybean herbicides Basagran (bentazon), Lasso (alachor), and Lexone 4L (metribuzin) was comparable to the untreated control, but the severe damage sustained by 50 percent of the seedlings on the Lasso+Lexone 4L treatment was considered excessive. Pine damage was comparable to the untreated control on the Atrazine 80W (atrazine), Bladex 4L (cyanazine), Atrazine 80W+Bladex 4L, and both Goal 2E (oxyfluorfen) treatments.

There was a severe drought in 1980 growing season, and considering all treatments, 31 percent of the loblolly pine seedling were classed as sustaining severe damage in the 1980 field test (table 1). Pine damage by the soybean herbicide Surflan A.S. (oryzalin) was comparable to the untreated control at both rates of application, as was pine damage on the Atrazine 80W+Bladex 4L and Goal 2E treatments. The two Velpar treatments averaged 75 percent more seedlings in the severe category than the untreated control.

In the 1987 field test, loblolly pine seedling survival across all treatments averaged over 99 percent (data not shown), and there was adequate soil moisture throughout the growing season. Pine groundline diameter growth for the 1-yr period averaged 0.8 cm on the untreated controls. This diameter growth rate was exceeded on the late winter and three spring treatments in March, April, May, and June 1987 (table 2). Pine diameter growth was comparable to the untreated control on the July, August, and September treatments.

Pine height growth for the 1-yr period averaged 43 cm on the untreated control, and this was comparable to the average height growth of 49 cm for pines on plots treated with Oust+Velpar L in March, April, May, and June 1987 (table 2). Pine height growth averaged 37 cm for the summer applications with Oust+Velpar L in July, August, and September 1987.

The gains in volume response for the 1-yr period were greatest in April and May (average of 243 cm^3), with the preceeding and following monthly treatments averaging a gain in volume response of 173 cm^3 (table 2). Pine trees on the untreated control and those receiving the July and August treatments had an average gain in volume response of 90 cm^3, while those treated with Oust+Velpar L in September 1987 had a gain in volume response of 46 cm^3.

Herbaceous Plant Control

In the 1979 field test, the soybean herbicides Basagran, Lasso, and Lexone 4L did not control the herbaceous vegetation, and the Lasso+Lexone 4L tank mixture was also ineffective (table 1). With the exception of Velpar, which provided excellent control, the remainder of the herbicides shown in table 1 gave fair to good herbaceous plant control through August 1979.

In the 1980 field test, the soybean herbicide Surflan A.S. provided good herbaceous plant control through August (table 1). The other herbicides gave good to excellent control of the herbaceous vegetation.

In the 1987 field test, the percentage of plot surface bare of vegetation ranged from 87 to 91 percent through October across all seven Oust+Velpar L treatment dates (table 2), so this treatment was effective the entire growing season with the exception of escaped bluestem, which was not injured. For the untreated control, 68 percent of the plot surface was bare of vegetation.

DISCUSSION

None of the four tested soybean herbicides caused damage to loblolly pine seedlings during the first growing season in the field. This suggested that soil residues from yearly applications of Basagran, Lasso, Lexone 4L, and Surflan A.S. should not reach toxic levels in old fields. However, only Surflan A.S. was useful as a herbaceous plant control agent in these tests. Surflan A.S. was also successfully used on a demonstration area in 1981 (undocumented work) for weeding around established slash pine seedlings (Pinus elliotii Engelm. var. elliotii).

Atrazine 80W, Goal 2E, and Bladex 4L did not injure loblolly pine seedlings either, and all three treatments were also effective as herbaceous plant control agents. Atrazine 4L (atrazine) and Goal 2E have both been successfully used in a long-term research study as herbaceous plant control agents (Haywood 1988). Creighton and others (1987) reported significant gains in loblolly pine height and diameter with applications of Goal 2E. Longleaf pine (Pinus palustris Mill.) also had increased height growth after one and two yearly treatments with Goal 2E (Nelson and others 1982).

Although Velpar damaged pine seedlings, it was considered the best herbicide among those tested for herbaceous plant control. The use of Velpar at 1.0 and 2.0 lb ai/acre has been shown to increase the biomass of seedling loblolly pines during the first growing season in Arkansas and Oklahoma (Nelson and others 1981).

Table 1.--Loblolly pine damage in June 1980 (1979 field test) and in May 1981 (1980 field test) and herbaceous plant control through August for each respective field test[1]

Application date and herbicides	Chemical common name	Active ingredient	Pine damage category Slight	Moderate	Severe	Herbaceous plant control
		lb/acre	percent			
			1979 Field Test			
March 13, 1979						
Atrazine 80W	atrazine	2.8	100	0	0	Fair
Bladex 4L	cyanazine	4.0	75	0	25	Fair
Atrazine 80W +Bladex 4L		2.8 2.8	75	0	25	Good
Lasso	alachor	3.0	83	0	17	Poor
Lexone 4L	metribuzin	0.5	100	0	0	Poor
Lasso +Lexone 4L		2.0 0.5	50	0	50	Poor
April 17, 1979						
Basagran	bentazon	1.0	100	0	0	Poor
Goal 2E	oxyfluorfen	1.0	92	8	0	Fair
Goal 2E		2.0	66	17	17	Good
May 16, 1979						
Velpar[2]	hexazinone	3.6	0	0	100	Excellent
Velpar		7.2	0	0	100	Excellent
Untreated control			79	0	21	Poor
			1980 Field Test			
February 6, 1980						
Velpar		3.6	45	0	55	Excellent
March 14, 1980						
Velpar		0.9	45	5	50	Excellent
Atrazine 80W +Bladex 4L		2.8 2.8	65	0	35	Excellent
Surflan A.S.	oryzalin	2.0	60	0	40	Good
Surflan A.S.		4.0	90	0	10	Good
April 24, 1980						
Goal 2E		2.0	70	0	30	Good
Untreated control			70	0	30	Poor

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[1] See text for explanation of damage categories and herbaceous plant control ratings.

[2] Velpar is a water soluable powder formulation.

Velpar L was applied with Oust without damage to pines in early spring, and gains in pine development were observed (table 2). The apparent lack of damage to the pines was encouraging because the herbicides were applied at too high a rate as evidenced by the failure of vegetation to recover after treatment (except for escaped bluestem) despite treatment date.

The March 6 application of Oust+Velpar L did not increase growth. This may have been because the pines had been planted on March 5. The planting hole may not have been sealed sufficiently to keep excessive amounts of herbicides from concentrating adjacent to the new root tips. Application in late spring and summer did not increase pine growth either, and a late summer application caused a decrease in growth. This suggests that an Oust+Velpar L tank mixture should be applied no sooner than 1 month after planting to allow for closure of the planting hole and before mid-May to take advantage of early spring rains and milder temperatures.

Table 2.--The gain in loblolly pine growth and a measure of volume response from March 1987 to March 1988, by date of treatment with Oust+Velpar L, and percentage of plot surface bare of vegetation in October 1987[1]

1987 Application date	Gain in loblolly pine growth and volume response for the 1-yr period			Plot surface bare of vegetation
	groundline diameter	height	volume response[2]	
	cm	cm	cm^3	percent
March 6	1.2	47	167	90
April 8	1.4	51	265	90
May 6	1.3	50	221	88
June 15	1.3	47	178	89
July 9	0.9	36	85	88
August 6	0.9	38	105	87
September 2	0.6	38	46	91
Untreated control	0.8	43	79	68

[1] Common names and rates of active ingredient for Oust (sulfometuron methyl) at 0.4 lb/acre, and Velpar L (hexazinone in a water dispersable liquid formulation) at 1.0 lb/acre.

[2] Volume response was the groundline diameter squared, then multiplied by height in centimeters.

The product Velpar L is labeled for use in 2-yr-old (or older) pine stands for release, but some pine damage should be expected. Nevertheless, Velpar L has been used successfully for herbaceous plant control without apparent loblolly pine damage at 0.5 to 1.5 lb ai/acre in the first and second growing seasons (Creighton and others 1987, McKee and Wilhite 1988) and at 1.0 lb ai/acre in the third and fourth growing seasons in the field (Haywood 1988). Three other hexazinone products--DPX-3674, DPX-3674-10P, and Velpar Gridball--have been used successfully in studies at 2.0, 6.0, and 2.0 lb ai/acre, respectively, without injuring newly planted loblolly pine seedlings (Fitzgerald and Fortson 1979, Haywood 1980, Haywood and Melder 1982).

Oust applied alone at 0.8 lb ai/acre increased the first growing season height and diameter growth of loblolly pines significantly (Neary and others 1985). After a broadcast treatment of Oust at 0.4 lb ai/acre at the beginning of the first growing season, loblolly pine height, diameter, and biomass increased through three growing seasons significantly on sites where woody vegetation was also treated by another method (Bacon and Zedaker 1987, Zutter and others 1987). Oust+Velpar L treatments at 0.1 to 0.5 and 0.5 to 1.0 lb ai/acre, respectively, have been shown to increase pine height and diameter significantly, but pine survival was reduced in certain situations (Creighton and others 1987, Yeiser and others 1987).

Clearly, the products developed for control of weeds in soybean fields were generally not useful on these loblolly pine planting sites. However, soil residues of herbicides were not a problem either. Oust and Velpar L were the best herbicides tested when both loblolly pine seedling tolerance and herbaceous plant control were considered.

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THE IMPACT OF HERBICIDES ON LOBLOLLY PINE PLANTATION ESTABLISHMENT IN EAST TEXAS[1/]

Stephen H. Schoenholtz and Brad L. Barber[2/]

Abstract.--Studies were established to determine the first-year response of planted loblolly pines to herbaceous weed control and to overstory deadening. Seedling survival was not significantly improved by herbicide treatment. April applications of either hexazinone + sulfometuron methyl or glyphosate + sulfometuron methyl for herbaceous weed control increased seedling volume index increment by up to 338% over the check. March or May applications of glyphosate + sulfometuron methyl decreased pine survival and growth. On the wooded sites, April application of liquid hexazinone produced the greatest first-year seedling growth.

INTRODUCTION

Loblolly pine (Pinus taeda L.) plantation establishment on the Upper Coastal Plain in East Texas is frequently limited by late spring and summer droughts. High mortality of pine seedlings on droughty sites may require the expense of replanting or may result in plantation abandonment. This situation often occurs on non-industrial private lands which have received inadequate site preparation to promote seedling establishment. Pine plantations are often planted by non-industrial private landowners either on small tracts of land that were pastured, or in residual, low-quality hardwood stands. Pastures have often been fertilized and have dense herbaceous covers dominated by bermudagrass (Cynodon dactylon L. Pers.), whereas arborescent species in the hardwood stands frequently limit pine seedling establishment. Pine establishment and productivity on these sites can be decreased by interspecific competition for soil moisture, nutrients, and light.

Studies by Carter and others (1984), Nelson and others (1981), and Zutter and others (1986) have documented improved soil moisture conditions resulting from herbaceous weed control on sites in the southeastern U.S. While recent studies have demonstrated improved loblolly pine establishment using herbicides to control herbaceous competition (Carter and others 1984; Creighton and others 1987; Knowe and others 1985; McKee and Wilhite 1988; Michael 1985; Nelson and others 1981; Tiarks and Haywood 1986; Zutter and others 1986), few have investigated the effect of herbaceous weed control on newly planted loblolly pine seedlings in droughty areas of East Texas.

Campbell (1985), Cantrell and others (1986), Kossuth and others (1980), McLemore (1984), Michael (1985), and Miller (1988) have reported on recent progress using herbicides to control individual unwanted hardwood stems; however, little information on the effects of these treatments on newly planted loblolly pine seedlings has been published.

Because of this lack of information, two studies were established based on the need to improve pine plantation establishment success on droughty sites in East Texas. A herbaceous weed control study was designed to evaluate the response of newly planted loblolly pines to a variety of herbicides applied to bermudagrass pastures at different dates. The release of newly planted loblolly pines from overstory hardwood competition using a variety of herbicides at different dates was also assessed. This paper summarizes the first-year results of these studies.

[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN November 1-3, 1988.

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STUDY SITES

Four sites scheduled for operational tree planting by the Texas Forest Service were used for each study. The sites were located in Anderson, Cherokee, Houston, Smith, and Waller Counties, East Texas (fig. 1). This area represents the westernmost distribution of loblolly pine and is characterized by inconsistent precipitation during the growing season. Well-drained, fine sandy loam soils predominated on all of the study sites. The herbaceous weed control studies were established on bermudagrass pastures. The hardwood control studies were established on sites with unwanted hardwood stands. Average basal area of the stands was approximately 70 ft^2/acre composed largely of post oak (Quercus stellata Wangenh.) and hickories (Carya spp.).

MATERIALS AND METHODS

Herbaceous Weed Control Study

The herbaceous weed control study was initiated in 1985 and 1986 with the establishment of two study sites each year. In 1985, the study was established at sites in Cherokee and Houston Counties. In 1986, the study was expanded to two additional sites located in Anderson and Cherokee Counties (fig. 1).

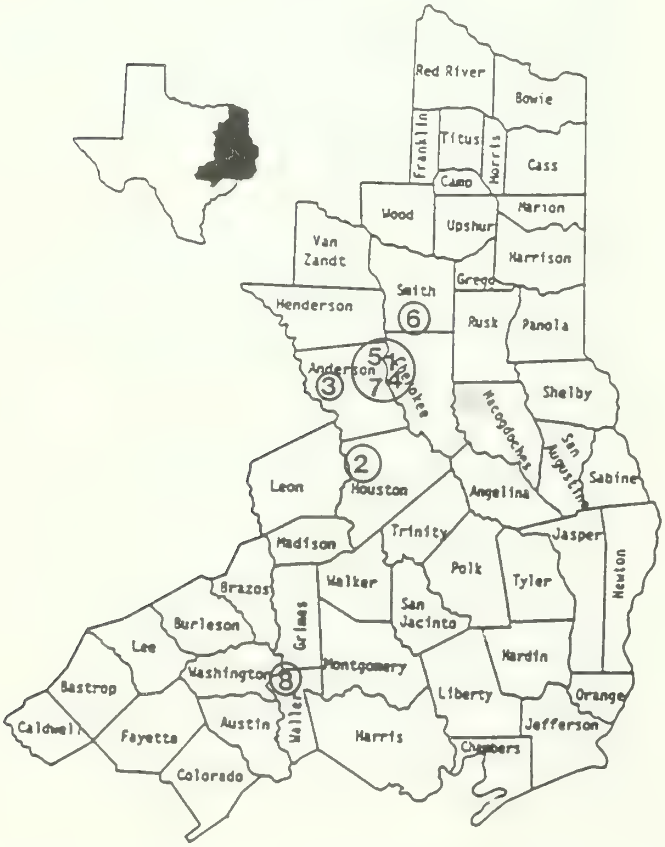

Figure 1.--Study site locations in East Texas.

Eight herbicide treatment combinations of different chemicals and application dates and a check (table 1) were replicated three times in a randomized complete block design at three of the four locations. At Site 1, six herbicide treatment plots and a check plot were replicated three times in a randomized complete block design (table 1). Plots were approximately 0.11 acres and consisted of seven rows with seven test trees in each row. Two rows of non-test trees bordered each plot to provide buffer zones between treatments. Genetically improved 1-0 loblolly pine seedlings selected for drought hardiness were acquired from the Texas Forest Service's Indian Mound State Tree Nursery and were machine-planted on 6 x 10 ft spacing in January, 1985 at Sites 1 and 2, and in January, 1986 at Sites 3 and 4. Herbicides were applied directly over the rows of seedlings in a three ft band with a Solo Model 425 backpack sprayer. Liquid hexazinone as Velpar L, a hexazinone + sulfometuron methyl mixture as Velpar L + Oust, and a glyphosate + sulfometuron methyl mixture as Roundup + Oust were tested using label-recommended rates at a pre-planting date and at a number of different post-planting dates (table 1).

Treatment effects on percent herbaceous cover, first-year pine seedling survival, stem volume index increment, and plot volume index (P.V.I.) were evaluated. A cylindrical volume calculation (height x ground-line diameter^2) was used for the stem volume index. The P.V.I. was calculated using stem volume estimates at the end of the first growing season for all trees in a plot, including dead tree stem volume values of zero. This provided a seedling performance index which incorporated both survival and volume growth responses. Initial measurements of seedlings were collected within two months of the planting dates, and prior to seedling growth, to test for initial plot differences which preceded the post-planting herbicide applications. First-year measurements of seedling response were collected in late October, 1985, at Sites 1 and 2, and in late October, 1986, at Sites 3 and 4. At all sites, visual estimates of percent herbaceous cover were conducted in August of the first growing season.

Analysis of variance was used to evaluate treatment effects on herbaceous cover and on pine performance. Percent values were compared statisically following an arcsine transformation. Duncan's multiple range test was used for mean separations.

Underplanting Release Study

The underplanting release study was initiated in 1985 and 1986 with the establishment of two study sites each year. The 1985 studies (Sites 5 and 6) were established in Anderson and Smith Counties, whereas the 1986 studies (Sites 7 and 8) were located in Anderson and Waller Counties (fig. 1).

Table 1.--Herbaceous weed control sites in East Texas and associated treatments

Year	Site	County	Herbicide	Rate	Application Date
				(lb a.i./acre)	
1985	1	Cherokee	hexazinone	0.75	4/85 5/85 6/85
			hexazinone+sulfometuron methyl	0.50+0.19	4/85 5/85 6/85
	2	Houston	hexazinone	0.75	10/84 4/85 5/85 6/85
			hexazinone+sulfometuron methyl	0.50+0.19	10/84 4/85 5/85 6/85
1986	3	Anderson	hexazinone+sulfometuron methyl	0.50+0.19	10/85 3/86 4/86 5/86
			glyphosate+sulfometuron methyl	0.75+0.19	10/85 3/86 4/86 5/86
	4	Cherokee	hexazinone+sulfometuron methyl	0.50+0.19	10/85 3/86 4/86 5/86
			glyphosate+sulfometuron methyl	0.75+0.19	10/85 3/86 4/86 5/86

The study design at each site was a randomized complete block with three replications of either nine or twelve hardwood control treatment combinations of chemicals and application dates and a check. Plots were approximately 0.25 acres and contained pine seedlings obtained as described above. They were hand-planted at 6 x 10 ft spacing in January, 1985 or 1986. Seven rows with seven seedlings per row were measured in each plot.

At Sites 5 and 6, three herbicides were applied at label-recommended rates in mid-April, mid-May, or mid-June, 1985. Undiluted dicamba as Banvel CST and undiluted picloram + 2,4-D as Tordon 101R were injected into hardwood trees with hypo-hatchets at a rate of one ml per injection at 1 inch spacings around the tree stem at breast height. Liquid hexazinone as Velpar L was diluted 1:1 (v/v) with water and applied to the base of each stem with a spot-gun applicator at a rate of one 2 ml spot per 1 inch diameter at breast height. At Sites 7 and 8, April, May, and June applications of undiluted triclopyr as Garlon 3A at a rate of one ml per injection at 1 inch spacings around the tree stem at breast height were also evaluated.

A complete hardwood inventory of the study sites was conducted prior to chemical treatments and again in October following the first growing season to determine the percentage of trees with complete canopy defoliation. Trees were listed as living or dead and a tree was considered dead only if its canopy was totally defoliated. Height and ground-line diameter measurements of the pine seedlings were collected prior to (March) and at the end (November) of the first growing season to determine first-year survival, stem volume index increment, and P.V.I.

Analysis of variance was used to evaluate treatment effects on hardwood kill and pine performance. Percent values were statistically compared following an arcsine transformation. Duncan's multiple range test was used for mean separations.

RESULTS AND DISCUSSION

Herbaceous Weed Control Study

Herbaceous Cover.--The amount of herbaceous cover observed in August of the first growing season was not significantly affected by any of the herbicide treatments at Sites 1 or 2 (table 2). This was due to a high degree of cover variability among the plots at Site 1, and to rapid reestablishment of herbaceous cover at Site 2. Sites 3 and 4 did show significant decreases in herbaceous cover with herbicide treatments (table 2). As expected, the percent cover measured in August of the first growing season decreased with later herbicide application dates. At any one application date, the efficacy of hexazinone + sulfometuron methyl and glyphosate + sulfometuron methyl mixtures was comparable.

Pine Survival and Growth.--Initial measurements indicated no significant differences in pine survival, height, ground-line diameter, or stem volume index among the plots prior to post-planting herbicide applications at any of the sites. Pine seedling survival after the first growing season at all of the sites was not improved by the herbicide treatments (table 2). In fact, at Sites 3 and 4, applications of the glyphosate + sulfometuron methyl mixture in March or May decreased seedling survival. Use of glyphosate for direct spraying over pines is recommended during periods of pine dormancy because it is a foliar-active herbicide. In this region of Texas, initial loblolly pine shoot elongation usually occurs in March, followed by a period of bud formation in April, and a second shoot elongation in May. As a result, the increased pine mortality in March and May may have been associated with increased herbicide sensitivity of the new needles and succulent stems. Cuticular development on newly elongated needles in April may have been adequate to impede herbicide uptake, whereas elongating stems and needles in March and May were more apt to absorb glyphosate prior to complete cuticular development.

Despite a lack of herbaceous control as measured in August, first-year stem volume growth of seedlings at Sites 1 and 2 was significantly improved by April applications of either herbicide treatment (table 2). At both of these sites, the April hexazinone + sulfometuron methyl mixture produced the largest first-year volume increment of any treatment. The volume gains were 338 and 294 % over the checks for Sites 1 and 2, respectively. May applications of hexazinone at both sites, and o hexazinone + sulfometuron methyl at Site 2 also increased stem volume growth over the check plots, but not to the same extent as the April treatments. These volume-growth results were closely reflected in the comparison of P.V.I. values (table 2). This indicated that the treatments that produced the best stem volume growth also had good seedling survival.

The lack of significant performance improvements with June herbicide applications a Sites 1 and 2 prompted the elimination of this application date at Sites 3 and 4. The effectiveness of April herbicide treatments als prompted the addition of March application date at Sites 3 and 4 to investigate pine performanc response to treatments applied earlier in the growing season.

Volume growth and P.V.I. were not significantly improved by any of the treatments at Site 3 (table 2). The negative effect of March and May applications of the glyphosate + sulfometuron methyl mixture on pine performance was indicated by volume increments of only 9.1 and 6.3 cc, respectively, compared to the 20.7 cc volume increment of the check plots. This poor growth response, in combination with low survival, resulted in significant P.V.I. reductions for these two treatments (table 2). At Site 3, higher survival and volume growth obtained with April application of glyphosate + sulfometuron methyl resulted in a significant P.V.I. increase compared to that of April applications of hexazinone + sulfometuron methyl (table 2). This suggests that the glyphosate + sulfometuron methyl mixture has the potential t provide beneficial pine seedling responses when applied within a relatively narrow period.

This study demonstrated that both herbicide mixtures significantly increased pine volume increment and P.V.I. at the April application dates at Site 4. The March application of hexazinone + sulfometuron methyl also significantly improved volume growth and P.V.I. The detrimental effect of March and May applications of glyphosate + sulfometuron methyl on P.V.I. observed at Site 3, occurred at this site but was not statistically significant.

Underplanting Release Study

Hardwood Defoliation.--Hardwood defoliation results at all four sites demonstrated that April, May, or June herbicide applications were equally effective (table 3). However, at any given application date, there were differences in hardwood defoliation among the herbicide treatments. At Sites 5 and 6, hexazinone was consistently superior with greater than 80 % of the trees being defoliated at all application dates. The percentage of trees defoliated by picloram + 2,4-D ranged from 65 to 81 % at these two sites. With the exception of a low

Table 2.--Effect of herbicide treatments on herbaceous cover and first-year loblolly pine performance on bermudagrass pastures in East Texas

Treatment	Percent Cover	Survival	Stem Volume Increment[1]	PVI[2]	Percent Cover	Survival	Stem Volume Increment	PVI
	(%)	(%)	(cc)	(cc)	(%)	(%)	(cc)	(cc)
	Site 1				Site 2			
Check	83a[6]	19.7a	3.9c	1.1b	80a	65.3a	4.8d	6.0c
Oct.								
H[3]	--[7]	--	--	--	87a	50.3a	5.8d	5.8c
H+S[4]	--	--	--	--	90a	57.8a	9.2bcd	8.5bc
Apr.								
H	53a	42.2a	10.7b	5.6b	80a	83.7a	14.3ab	15.1ab
H+S	20a	57.8a	17.1a	11.1a	77a	87.1a	18.9a	19.9a
May								
H	47a	41.5a	10.7b	5.0b	87a	59.9a	12.2bc	9.4bc
H+S	40a	48.3a	9.8bc	5.9b	83a	70.1a	14.6ab	13.2ab
June								
H	20a	49.7a	6.2bc	4.7b	90a	46.9a	5.8d	4.9c
H+S	50a	40.1a	6.0bc	3.6b	87a	48.3a	6.1cd	5.0c
	Site 3				Site 4			
Check	100a	76.9ab	20.7a	16.8abc	100a	93.9a	13.1cd	14.4cd
Oct.								
H+S	97ab	85.7a	13.0a	12.8abcd	93ab	93.9a	19.1cd	19.9c
G+S[5]	90abc	86.4a	17.2a	16.8abc	93ab	92.5a	22.7bc	22.8bc
Mar.								
H+S	80cd	87.8a	19.2a	18.6ab	77bc	91.8a	33.2ab	32.1ab
G+S	83bcd	38.1cd	9.1a	4.2d	93ab	74.2bc	16.9cd	14.0cd
Apr.								
H+S	70cde	78.9ab	11.6a	11.0bcd	70c	87.8ab	41.8a	38.5a
G+S	57def	86.4a	24.6a	23.0a	73c	95.2a	33.7ab	33.8a
May								
H+S	33f	57.8bc	10.5a	7.3cd	40d	83.0abc	22.2bcd	20.0c
G+S	50ef	30.6d	6.3a	2.4d	20d	65.3c	9.2d	7.4d

[1] Height x diameter^2.
[2] Plot volume index.
[3] Hexazinone.
[4] Hexazinone + sulfometuron methyl.
[5] Glyphosate + sulfometuron methyl.
[6] For each site, means within a column followed by different letters are significantly different at the 0.05 level according to Duncan's multiple range test.
[7] Site 1 did not receive herbicide treatments in October.

Table 3.--Effect of herbicide treatments on hardwood defoliation and first-year loblolly pine performance on hardwood sites in East Texas

Treatment	Hardwood Defoliation[1]	Survival	Stem Volume Increment[2]	PVI[3]	Hardwood Defoliation	Survival	Stem Volume Increment	PVI
	(%)	(%)	(cc)	(cc)	(%)	(%)	(cc)	(cc)
	Site 5				Site 6			
Check	1f[7]	96.6a	4.4b	7.4d	3f	94.6a	2.7d	6.3cd
April								
dicamba	39de	94.6ab	5.3b	8.0cd	60cd	94.6a	4.1d	7.7cd
pic.+D[4]	65bcd	92.5ab	6.6b	8.7bcd	72b	92.5a	6.5cd	9.3c
hexaz.[5]	95a	87.8ab	25.9a	25.2a	98a	95.6a	19.4a	22.0a
May								
dicamba	38e	88.4ab	5.0b	7.2d	46e	89.8a	2.1d	4.1d
pic.+D	81ab	92.5ab	8.6b	11.4b	68bc	95.2a	4.7cd	7.7cd
hexaz.	91a	90.5ab	8.6b	10.6bc	100a	96.6a	11.2bc	14.4b
June								
dicamba	51cde	93.2ab	4.5b	7.0d	52de	89.8a	4.0d	7.3cd
pic.+D	72abc	93.9ab	5.5b	8.2cd	65bc	92.5a	1.9d	5.3cd
hexaz.	83ab	91.8ab	5.6b	8.0cd	95a	95.2a	5.0cd	8.3c
	Site 7				Site 8			
Check	0d	46.9a	4.3c	3.0b	1e	66.7a	1.4e	1.8d
April								
dicamba	30c	39.5a	7.6bc	4.1b	43cd	79.6a	2.8de	3.3d
pic.+D	75ab	46.9a	10.9b	6.0b	90a	71.4a	4.1cde	4.0cd
hexaz.	73ab	40.8a	8.7bc	4.2b	97a	87.8a	9.9a	9.9a
tricl.[6]	76ab	47.6a	10.2bc	5.7b	100a	79.6a	8.7ab	8.1ab
May								
dicamba	51bc	53.7a	7.8bc	5.6b	30cd	76.2a	2.2de	2.4d
pic.+D	71ab	50.3a	7.7bc	4.9b	72ab	72.1a	2.4de	2.7d
hexaz.	95a	58.5a	16.7a	10.5a	96a	78.9a	6.4bc	6.3bc
triclo.	80a	40.1a	8.0bc	3.9b	96a	68.0a	3.1de	2.9d
June								
dicamba	27c	42.9a	5.4bc	3.5b	22de	70.7a	2.1de	2.4d
pic.+D	78ab	41.5a	6.7bc	3.6b	55bc	70.7a	2.3de	2.5d
hexaz.	78ab	53.1a	5.8bc	4.3b	93a	70.7a	4.4cde	4.1cd
triclo.	85a	41.5a	6.7bc	3.8b	95a	59.9a	5.1cd	4.0cd

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[1] Percentage of trees with complete defoliation.

[2] Height x diameter^2.

[3] Plot volume index.

[4] Picloram + 2,4-D.

[5] Liquid hexazinone.

[6] Triclopyr.

[7] For each site, means within a column followed by different letters are significantly different at the 0.05 level according to Duncan's multiple range test.

defoliation value for the June application of picloram + 2,4-D at Site 8, the use of triclopyr, picloram + 2,4-D, or hexazinone was equally effective for hardwood defoliation at Sites 7 and 8. Greater than 70 % of the trees were completely defoliated by each of these treatments. Dicamba applications produced the lowest number of trees with canopy defoliation at all four sites. The number of trees defoliated using dicamba ranged from 22 to 60 % (table 3). This suggests that dicamba may not be suitable for hardwood control on sites which are dominated by post oak and hickories.

Pine Survival and Growth.--Initial measurements taken prior to herbicide applications indicated no significant differences in pine survival, height, ground-line diameter, or stem volume index at any of the sites. First-year survival of the underplanted loblolly pines was not significantly affected by the herbicide treatments at any of the four sites (table 3). However, some of the treatments resulted in increased volume growth and P.V.I. of the pines. The most notable pine-performance improvement occurred with April application of hexazinone at Sites 5,6, and 8. At Site 7, the May application of hexazinone was most effective. May applications of hexazinone at Sites 5,6, and 8 also significantly increased P.V.I., but not to the same extent as April applications. Increased volume growth and P.V.I. under all of the other treatments were inconsistent (table 3).

CONCLUSIONS

Pine performance data from the four herbaceous weed control sites in East Texas suggest that April applications of hexazinone + sulfometuron methyl provide the most consistent benefits. Although herbaceous cover was usually re-established by August with this treatment, the reduction in interspecific competition during late April and throughout May was adequate to consistently improve pine response on all sites. The lack of response to applications of herbicides in May and June can be attributed to the decrease in active seedling growth in mid-summer when the herbicide efficacy with these treatments is maximized. Thus, most seedling growth had occurred before the herbicide treatments decreased competition. Applications of herbicides prior to planting eliminated direct spray exposure of the pine seedlings; however, these bermudagrass pastures recovered rapidly and negated herbicide benefits for pine performance. The negative effects of March and May applications of glyphosate + sulfometuron methyl indicate that spraying of this mixture should be limited to periods when seedling stems and needles are not elongating.

Results of the underplanting release study suggest that the effects of hardwood defoliation did not occur early enough during the first growing season to significantly alter underplanted pine performance. However, the effect of arborescent control should become more evident in future years. The first-year growth response to April and May applications of hexazinone was probably a function of the herbaceous weed control provided by these treatments rather than a response to hardwood control. This dual benefit, in combination with the relative ease and worker safety associated with spot-gun applications, suggests that this may be the most effective treatment for these types of sites in East Texas.

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RAPID PRIMARY SCREENING FOR FORESTRY HERBICIDES[1]

Shepard M. Zedaker and John R. Seiler[2]

Abstract.--A rapid screening technique for the effects of herbicides on forest trees has been developed that accelerates the normal field screening process. Containerized and/or potted seedlings are grown in a combination of greenhouse and field environments in cycles that permit primary screens to be accomplished in six to eighteen months. Accelerated screening trials using existing herbicides have resulted in efficacy similar to field trials. The screening trial design characteristics and methodology are presented.[3]

INTRODUCTION

The application of herbicides for silvicultural operations has increased as the management of southern forests has intensified. Several new chemicals have been introduced in the past decade for forestry uses but the number of new herbicides is miniscule in comparison to those produced for food crops over the same period. The development of new herbicides follows a consistent pattern of testing. Primary screening is the first step and is designed to determine if there is any herbicidal activity at all over a wide range of chemical rates. Many barriers to the development of new herbicides for woody plant control exist; not the least of which are the time and cost associated with woody plant primary chemical screening.

In herbaceous plant primary screening, very small amounts (milligrams or less) of newly formulated herbicides are applied to flats containing several different species of weed and crop plants. The plants are grown in greenhouses and the entire screen, from application to final assessment, usually takes less than 60 days. In contrast, the primary screen of herbicides for woody plant control in forests usually takes place outside in relatively large field plots and is not completed until responses from two growing seasons have been recorded. To insure that an adequate number of individuals of several different species are screened (a minimum of 50 individuals per species), field plots on the order of 1/20 to 1/5 ha per chemical-rate-replication are needed. If additional factors like soil texture, season of application, carrier concentration, etc. are studied the amount of the newly formulated chemical needed for the screen becomes extremely large. Since new chemicals can be formulated only a few grams or less at a time, any substantial field trial with adequate replication at usual application rates (100 grams to 1 kilogram per ha) becomes prohibitively costly.

The time required for woody plant screening in the field is also a barrier. Woody perennials are long-lived and their response to herbicide applications is often quite slow. It is not uncommon for herbicides to take two growing seasons after application to manifest their full effect. As a consequence, the usual field screen of a woody plant herbicide takes 17 to 26 months to complete (table 1).

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Table 1. Field Screening Timetable

Spring Applications

Month	Event
1 (spring)	Spray
6-7 fall)	First Assessment
11-13 (spring)	Begin Cycle 2
17-20 (fall)	Second Assessment

Fall Applications

Month	Event
1 (fall)	Spray
7-8 (spring)	Begin Cycle 1
11-13 (fall)	First Assessment
19-20 (spring)	Begin Cycle 2
23-26 (fall)	Second Assessment

Because of the excessive time and large amount of chemical required, an herbicide is screened only after it has shown considerable promise in other, more lucrative, agricultural markets. It is not unthinkable that there could be many good red maple (Acer rubrum) control herbicides that got no further than a primary herbaceous plant screen simply because they killed soybeans (Glycine max) or corn (Zea mays) or did not kill pigweed (Amaranthus spp.) or Canada thistle (Cirsium arvense).

METHODS

The rapid screening technique was developed out of a necessity to produce seedlings with secondary woody tissue for herbicide uptake and translocation studies in less than a year. A combination of natural and artificial environments are used with containerized seedlings to produce hardened woody tissue in much less time than is normally required in nature. The technique compresses several before or after treatment growing seasons (actually growth-dormany cycles) into a single year. Ultimately, the screening cycle for woody plants is reduced 30 to 50 percent and the use of containerized seedlings decreases the chemical requirement several orders of magnitude to the gram and fraction of a gram levels.

The screening cycle begins with the planting of stratified seed or commercially obtained bare-root nursery stock in containers (table 2). Although the use of nursery stock reduces the time requirements for the primary screen by one to six months, the applicability and repeatability of the results may suffer. Herbicide efficacy is known to be strongly influenced by the physiological condition of the treated plants (D'Anieri et al. 1987). If the physiological condition of the commercially obtained nursery stock is unknown or varies from batch to batch, the screening trials may produce inconsistent results. We recommend starting with seed and maintaining a tightly controlled regimen of environmental treatments to produce seedlings with consistent physiological condition.

Table 2. Rapid Screening Timetable

Starting from nursery stock

Month	Event
1	Begin Cycle 1
2-3	Spray
3-4	Harden Off/First Assessment
4-5	Chill
6-7	Begin Cycle 2/Break Dormancy
9-12	Second Assessment

Starting from seed

Month	Event
1	Plant Seed
3-4	Harden Off
4-5	Chill
6-7	Begin Cycle 2/Break Dormancy
7-9	Spray
8-11	First Assessment/ Harden Off
9-12	Chill
11-14	Begin Cycle 3/Break Dormancy
13-16	Final Assessment

Container size and planting densities are customized to accommodate the natural growth pattern of individual tree species. Large seeded hardwood species like hickory (Carya spp.) and oak (Quercus spp.) require container sizes on the order of 500 to 1,000 cm^3. Small seeded hardwoods and conifers can be grown in 150 to 500 cm^3 containers. Density during the growth periods is dictated by container size but seedlings should be spread out during the actual spray operation to eliminate the possibility of screening the smaller seedlings from treatment. Although paper or compressed peat containers are the least expensive, plastic containers should be used. Paper or peat containers do not hold up to the frequent movement from one growth environment to another and spreading out of the seedlings during the spraying.

The growth medium for the containers can vary, depending on the potential soil activity of the chemistry under investigation. Again, consistency is important and a standard loam to sandy loam soil or course planting mixes of sand, peat and vermiculite are best if nothing is known about soil activity. Soil acidity and nutrient requirements must be adjusted to a level sufficient for the woody species in the primary screen.

Seedlings are rotated between greenhouses, shade houses, and cold rooms, depending on the natural time of year and the environmental conditions required for the growth cycle that is desired. The seedlings are exposed to natural outdoor growing conditions for dormancy breaking (spring), active growth (summer), hardening off (fall), and chilling (winter) periods whenever possible. Greenhouses and cold rooms are utilized to provide growing-season-like environments in the winter and dormant-season-like environments in the summer, respectively. Shade houses are utilized to provide transition/acclimation environments to avoid shock from too rapid environmental changes.

The specific environmental conditions (light, temperature, water, nutrients, etc.) necessary for each species of seedling in the primary screen during each of the different periods of the growing cycle must be maintained. A significant problem is determining a treatment regime sufficient for all the species in the screen since the optimum environmental conditions for different species and even different seed sources of the same species can be quite different. For example, sugar maple (*Acer saccharum*) collected in Canada requires over 2,000 hours of chilling to break bud dormancy while red maple collected from the southern part of its range requires little or no chilling (Kriebel and Wang 1962, Perry and Wang 1960).

Artificial environments that we have used to simulate the natural conditions for southern tree species during the growing season include: daytime temperatures between 25 and 35°C, nighttime temperatures 5 to 10° C cooler with 16 hour or longer photoperiods. Seedlings are generally kept well watered but brief periods of moderate water stress may be used to stimulate woody growth. Nutrients are kept at an optimum level by weekly additions of soluble fertilizer. Short days ($\leq$ 12 hours), cool temperatures (10 to 15° C), moderate water stress ($\geq$-1.0 MPa), and low nutrient availability (water only) are necessary to simulate the hardening off process. Chilling is carried out in temperatures between 0 and 5° C. Temperatures below freezing are unnecessary to meet the chilling requirements of most southern tree species and above freezing temperatures provide a margin of safety against cold temperature injury. Photoperiod during chilling is not critical but should be less than 12 hours. To break dormancy, long ($\geq$ 16 hour) warm ($\geq$ 25° C) days with optimum water and nutrition are needed.

Herbicides are applied in a calibrated spray-hood under much more tightly controlled conditions than can be accomplished in the field. Application rate variance is usually less than three percent and often less than one percent. Variance over the spray swath is minimized with multiple overlapping flat fan nozzles or a single, verified, even flat fan nozzle. In comparison, even under the best conditions, application variance within and among spray swaths in field trials is rarely below three percent and often above five percent.

Efficacy assessment is usually carried out in several stages. Early assessments during the same growth period as the herbicide application are visual estimates of percent foliar necrosis in pre-arcsine transformed classes. Subsequent assessments in growth periods after the applications include mortality, height and root crown diameter measurements, and dry weight expressed as percent control derived from these measures on untreated seedlings.

RESULTS AND DISCUSSION

Over the past five years, we have produced seedlings of seven different southeastern hardwood species, loblolly pine (*Pinus taeda*) and Douglas-fir (*Pseudotsuga menziesii*) and tested several different herbicides for efficacy and physiological mechanisms governing herbicide uptake. The rapid screening technique produced results similar to second year response data from field trials in 16 months from stratified seed. As might be expected, the rates used in rapid primary screening to produce efficacy results similar to those found in field trials have been 0.25 to 0.50 times those used in the field. Rate-plant size efficacy interactions are common and reinforce the need to produce consistently sized seedlings as opposed to accepting nursery run stock for rapid screens. As long as they are not shielded from the spray, smaller field-grown plants are generally killed at lower herbicide rates than larger plants of the same species.

The most important attribute of rapid screening techniques, tree species-chemical efficacy trends, seem consistent with field trials in the limited number of studies for which we have both field and rapid screen observations. For example, in a rapid screen of glyphosate on red maple, sweetgum (Liquidambar styraciflua) and loblolly pine, the 0.8 lbs ai/ac rate produced results remarkably similar to those obtained from commercial aerial applications of 1.5 lbs ai/ac. Sweetgum was easy to control, red maple was intermediate and loblolly pine was resistant to glyphosate damage (table 3). Consistent results have also been found in trials with unlabeled compounds. Field applications of fluroxypyr applied with a pole sprayer at 2.0 lbs ae/ac on red maple and sweetgum produced results similar to rapid screen applications at 0.5 lbs ae/ac (table 4).

Table 3. Comparison of glyphosate efficacy in 1984 commercial field applications for release at 1.5 lbs ai/ac with rapid screening applications at 0.8 lbs ai/ac on red maple loblolly pine and sweetgum.

	Species		
Application	Red Maple	Sweetgum	Loblolly Pine
		(% control)	
Commercial Field	53	92	15
Rapid Screen	55	91	43*

*Non herbicide induced mortality was unavoidably included.

Table 4. Comparison of fluroxypyr efficacy between a field application (2 lbs ai/ac) and rapid screening (0.5 lbs ai/ac).

	Species	
Application	Red Maple	Sweetgum
	(% control)	
Conventional Field	89	40
Rapid Screen	100	40

The most difficult procedure in the rapid screen technique is meeting the environmental demands of several different tree species during different stages of their growth cycle, concurrently. A mean physiological treatment schedule may have to be developed for groups of species so that separate greenhouse and cold room facilities are not needed for each species. Species with widely overlapping natural ranges and similar growth habits seem best adapted to a mean treatment schedule. For example, in some of our most recent rapid screening trials, yellow poplar (Liriodendron tulipifera), red maple, and sweetgum were easy to keep on the same schedule and had similar growth habits. However, southern red oak (Quercus falcata) and water oak (Quercus nigra), also in the screens, were quite different in their growth habits and required different treatment schedules.

CONCLUSIONS

Although our experience in rapid screening for forestry herbicides has been limited to nine tree species and only four herbicides, the consistency of the results with field screening and the significant time and chemical savings over field trials are encouraging. The technique should be easy to establish for any researchers familiar with both herbicide applications and containerized woody plant nursery production. One chemical company is already using a similar technique and several others have expressed an interest in its further development and refinement. The end result may be a dramatic increase in the number of newly formulated herbicides tested for woody plant control in forests and, if successful, the number of herbicides available for forest management should increase.

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RATIO AND REGRESSION ESTIMATORS OF HARDWOOD GROWTH FOR COMPARING EFFICACY OF HERBICIDE TREATMENTS[1]

Steven A. Knowe and Barry D. Shiver[2]

Abstract.--An objective procedure for comparing effectiveness of herbicide treatments is presented. Growth of hardwood rootstocks between treatment and evaluation can be obtained using ratio or regression estimators. Computational formulas and conditions for valid application of the estimators are discussed. Examples of both estimation procedures and their effect on statistical significance of orthogonal contrasts are demonstrated for dogwood and sweetgum in a site preparation study.

INTRODUCTION

Estimates of herbicide efficacy are essential for forest vegetation management. Chemical companies make marketing decisions and forest managers make treatment recommendations based on efficacy. In the current environment of budget reductions for research and operational forestry activities, accurate and precise efficacy estimates are required for comparing herbicide treatments.

Following the suspension of 2, 4, 5-T, several new herbicides were introduced for forest site preparation and release. Comparisons among the available herbicides necessitated some expression of treatment efficacy. In a review of published herbicide literature, Neill et al. (1982) observed that most pine release and site preparation studies which reported treatment efficacy used ocular estimates of defoliation or kill of target species. Although defoliation is relatively easy to obtain, it is very subjective and dependent on the evaluator, it does not account for differences in size of the target species, and it may not be related to subsequent crop response.

Zedaker and Lewis (1983) recognized the shortcomings of defoliation and proposed measuring stem or crown dimensions of the target species. These measurements not only reduce evaluator subjectivity, but some variables such as sum of rootstock heights (Zutter and Glover 1984) and sum of crown diameters (Knowe and Shiver 1988) have been correlated with pine-growth response.

The purpose of this study is to present a procedure for comparing herbicide treatments which is objective and reduces variation among treatments. Three methods of accounting for growth of hardwood rootstocks between pre- and post-treatment evaluations are presented. The effects of these methods on efficacy estimates, variances, and treatments contrasts are demonstrated using a site preparation study in the Georgia piedmont.

ACCOUNTING FOR HARDWOOD GROWTH IN EFFICACY ESTIMATES

When pre- and post-treatment stem or crown measurements are obtained for relocated hardwood rootstocks, efficacy can be calculated two ways. The first is to compute the difference between pre- and post-treatment hardwood size and express it as a percentage of pretreatment size (Eq. 1).

$$C_D = (H_O - H_E) \,/\, H_O \qquad (1)$$

where C_D = control based on change
H_O = pretreatment hardwood size
H_E = post-treatment hardwood size

Since C_D is a proportion relative to pretreatment size, it tends to underestimate control on treated plots especially when growth is suppressed without killing the rootstock. An expression of efficacy based on a proportion relative to expected post-treatment size in the absence of treatment (H) would provide a more reasonable estimate of control (Eq. 2).

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$$C = (\hat{H} - H) / \hat{H} \qquad (2)$$

where C = control based on growth

$\hat{H}$ = expected post-treatment hardwood size

The accuracy of an efficacy estimate calculated in this manner is determined by the ability to predict expected post-treatment hardwood size. Ratios and regressions are two estimation procedures which can be used to obtain $\hat{H}$. Cochran (1963) and de Vries (1986) present many of the theoretical and practical aspects of both types of estimators.

Ratio Estimators

Ratio estimators are based on a ratio between two means. In a herbicide effficacy study, R is estimated as the ratio between the mean of observed post-treatment size and the mean of observed pretreatment size of individual hardwood rootstocks on untreated plots in the experimental design (Eq. 3).

$$\hat{R} = \bar{H}^*_E / \bar{H}^*_O \qquad (3)$$

where $\bar{H}^*_E$ = mean post-treatment size on untreated plots.

$\bar{H}^*_O$ = mean pretreatment size on untreated plots

The ratio estimate assumes that the relationship between pre- and post-treatment size is constant throughout the range of pretreatment sizes, the regression is a straight line passing through the origin, and pre- and post-treatment sizes are positively correlated. Also, the variance of observed post-treatment size on untreated plots is assumed to be directly proportional to observed pre-treatment size on untreated plots.

Expected post-treatment size for an individual hardwood rootstock on any plot in the experiment is calculated as the product of the ratio and observed pretreatment size (Eq. 4).

$$\hat{H}_R = \hat{R}\, H_O \qquad (4)$$

where $\hat{H}_R$ = expected post-treatment size of an individual rootstock based on a ratio estimator.

$\hat{R}$ = ratio estimator from untreated plots.

H_O = observed pretreatment size of an individual rootstock on any plot.

The expression of efficacy based on a ratio estimate (C_R) is given in Eq. 5.

$$C_R = (\hat{H}_R - H_E) / \hat{H}_R \qquad (5)$$

Freyman and Zedaker (1987, 1988) have indirectly applied a ratio of growth in a pine release study. Miller (1988) used the mean of ratios for individual rootstocks, in directed spray and thinline studies, which assumes that the variance of post-treatment size is proportional to the variance of pretreatment size.

Regression Estimators

Regression estimators are based on linear regression procedures. In a herbicide efficacy study, the regression-based estimator of expected post-treatment size is a regression function using the mean observed pre- and post-treatment sizes or untreated plots and the observed pretreatment size of an individual rootstock (Eq. 6).

$$\hat{H}_{LR} = \bar{H}^*_E + \hat{\beta}\,(H_O - \bar{H}^*_O) \qquad (6)$$

where $\hat{H}_{LR}$ = expected post-treatment size of an individual rootstock based on a regression estimator.

$\hat{\beta}$ = slope of the regression equation.

$\bar{H}^*_E$ = mean post-treatment size on untreated plots.

$\bar{H}^*_O$ = mean pretreatment size on untreated plots.

H_O = observed pretreatment size of an individual rootstock on any plot.

The regression estimator adjusts the mean post-treatment size on untreated plots (H_E) according t how much the observed pretreatment size of an individual rootstock (H_O) is above or below the mean pretreatment size on untreated plots (H_O).

As with the ratio estimator, the regression estimator in Eq. 6 depicts a straight-line relationship between pre- and post-treatment size, but does not assume that the regression passes through the origin. Linear transformations of certain nonlinear models as well as multiple regressions may also be used. The variance of post-treatment size on untreated plots is assumed to be constant with respect to pretreatment size o untreated plots, but weighted regressions can be used to compensate for types of proportional variance.

The expression of efficacy based on a regression estimate (C_{LR}) is given in Eq. 7.

$$C_{LR} = (\hat{H}_{LR} - H_E) / \hat{H}_{LR} \qquad (7)$$

Knowe et al. (1987) and Kline et al. (1988) have used regression estimates to compare efficacy of herbicide treatments in a site preparation study.

DEMONSTRATION OF PROCEDURES

The effect of each method of accounting for hardwood growth is demonstrated with a site preparation study in the piedmont of Georgia. Details of installation, herbicide application, and hardwood rootstock location are presented by Knowe et al. (1987). The study consists of several rates, formulations, and combinations of Tordon^R (picloram with and without 2, 4-D), Garlon^R (triclopyr ester and amine formulations), and Velpar L^R (hexazinone), and an untreated control, with three replications of each treatment. Leaf-surface index (LSI), expressed as the product of crown height and crown diameter, is used as the measure of hardwood size before treatment, LSI (0), and two growing seasons after treatment, LSI (2).

Comparison of efficacy estimators are made for flowering dogwood (Cornus florida L.) and sweetgum (Liquidambar stryaciflua L.). Graphs of LSI (2) against LSI (0) and the ratio and regression estimators are presented for each species. Means are compared for change (C_D), ratio-based control (C_R), and regression-based control (C_{LR}). Finally, the effect of each method of accounting for hardwood growth on treatment comparisons is investigated by examining variances, represented by mean-squared error (MSE) from each analysis of variance and by comparing significance of mutually-orthogonal (independent) contrasts.

Graphs of post-treatment LSI against pretreatment LSI on the untreated plots are presented for dogwood and sweetgum in Figures 1 and 2, respectively. Both species exhibit relatively stable trends in the variance of LSI (2) relative to LSI (0). The ratio estimates are 2.10 for dogwood and 2.41 for sweetgum which indicate that both species more than double in size between pre- and post-treatment evaluations. Note also that the intercepts of both regression estimators are different from zero ($p < 0.05$). Using a ratio estimate for either species underestimates LSI (2) below the mean and overestimates LSI (2) above the mean.

Estimates of mean efficacy based on change, ratios, and regressions are compared in Table 1. In general, control based on change is less than control based on either the ratio or regression estimator, and control based on the ratio estimator is less than or equal to control based on the regression estimator. For dogwood, the differences and similarities among treatment means appear to be consistent across all three efficacy estimators. For sweetgum, the differences among the Tordon + Garlon treatments and the Velpar treatments appear to be larger for the regression-based estimates than for the ratio-based estimates of control.

The mean squared errors (MSE), which represent the population variance plus the bias squared from each analysis of variance, are compared in Table 2. Control based on change (C_D) results in the largest MSE, which is 4 to 5 times greater than for ratio-based control (C_R). Control based on the regression estimator (C_{LR}) produces the smallest MSE which is about a third less than for ratio-based control.

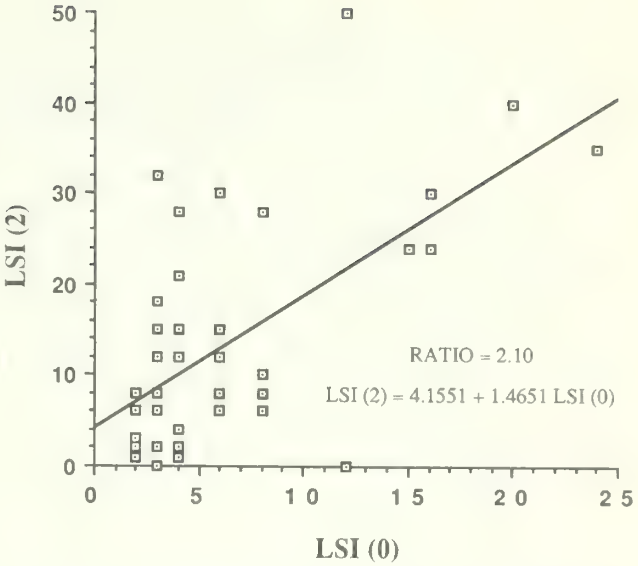

Figure 1.--Relationship between post-treatment LSI and pretreatment LSI for dogwood on untreated plots with ratio and regression estimators.

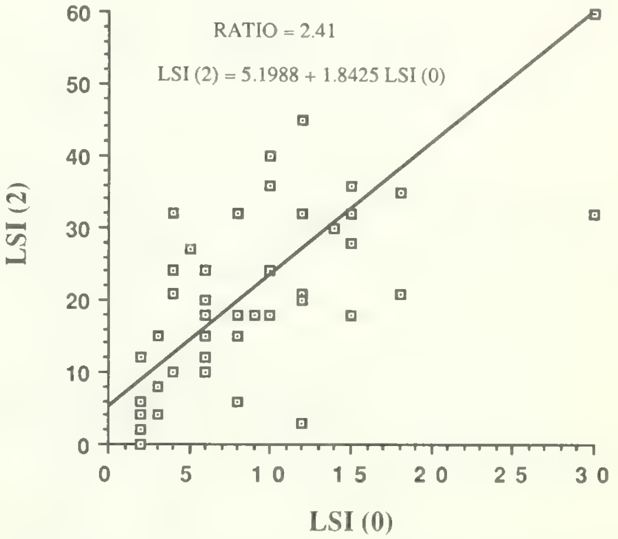

Figure 2.--Relationship between post-treatment LSI and pretreatment LSI for sweetgum on untreated plots with ratio and regression estimators.

Results of F tests for orthogonal contrasts are summarized in Table 3. The most obvious trend is that contrasts for control based on change have the same level of significance as control based on the ratio estimator. For dogwood, all three efficacy estimators result in the same conclusion for all contrasts with the regression-based estimator producing the most conservative (highest probability of greater F) tests. For sweetgum, Table 1.--Mean efficacy for dogwood and sweetgum using change, ratio-, and regression-based estimators of hardwood growth.

	Control of Dogwood			Control of Sweetgum		
Treatment	Change(C_D)	Ratio(C_R)	Regression(C_{LR})	Change(C_D)	Ratio(C_R)	Regression(C_{LR})
Tordon K + Garlon 4 (high)	1.00	1.00	1.00	0.70	0.87	0.87
Tordon K + Garlon 4 (low)	0.84	0.93	0.93	-0.03	0.57	0.65
Tordon 101 + Garlon 4	0.87	0.94	0.95	0.82	0.92	0.95
Garlon 4	0.66	0.84	0.87	0.35	0.73	0.76
Garlon 3A	-0.02	0.53	0.52	0.35	0.73	0.73
Garlon 3A + XRM4823	-0.08	0.50	0.53	0.55	0.81	0.84
Velpar L	-0.38	0.36	0.40	-0.24	0.49	0.62
Velpar + Tordon 101	-0.10	0.49	0.45	-0.45	0.40	0.50
Velpar + Garlon 4	-0.45	0.33	0.39	-0.88	0.22	0.21
Untreated Control	-1.48	-0.16	0.00	-1.76	-0.15	-0.01

Table 2.--Mean squared errors (MSE) from analysis of variance of efficacy based on change, ratio, and regression estimates of post-treatment size for dogwood and sweetgum.

Estimation Method	Dogwood	Sweetgum
Change (C_D)	1.4913	2.3224
Ratio (C_R)	0.3240	0.4006
Regression (C_{LR})	0.2352	0.2249

Table 3.--Significance (probability of greater F) for orthogonal contrasts of efficacy for dogwood and sweetgum using change, ratio-, and regression-based estimators of hardwood growth.

	Dogwood			Sweetgum		
Orthogonal Contrast	Change(C_D)	Ratio(C_R)	Regression(C_{LR})	Change(C_D)	Ratio(C_R)	Regression(C_{LR})
Control vs Herbicides	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Tordon + Garlon Trts vs Other Herbicides	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Garlon Trts vs Velpar Trts	0.0006	0.0006	0.0001	0.0001	0.0001	0.0001
Tordon + Garlon 4- K vs 101 Formulation	0.7579	0.7579	0.7912	0.1009	0.1009	0.0369
Tordon K + Garlon 4- High vs Low Rate	0.5306	0.5306	0.8204	0.0370	0.0370	0.0601
Garlon- Ester vs Amine Formulation	0.0027	0.0027	0.0004	0.6920	0.6920	0.7082
Garlon 3A- Alone vs XRM4823	0.8621	0.8621	0.9112	0.4949	0.4949	0.2148
Velpar- Alone vs w/Tordon or Garlon	0.5650	0.5650	0.7814	0.0969	0.0969	0.0010
Velpar + Tordon 101 vs Velpar + Garlon 4	0.1298	0.1298	0.4585	0.1454	0.1454	0.0016

conclusions for the contrasts vary between ratio- and regression-based controls. The contrast between Tordon formulations is not significant for control using a ratio estimator but is significant using the regression estimator. This implies that adding 2, 4-D to picloram in the Tordon 101 formulation results in better control of sweetgum. Also, the high and low rates of Tordon K + Garlon are different using a ratio to estimate hardwood growth but are not different using a regression estimator. Both contrasts involving Velpar and Velpar combination treatments are not significant for ratio-based control but are significant for regression-based control. The implication is that both Tordon 101 and Garlon 4 are antagonistic with Velpar, but the antagonism is even more pronounced with Garlon 4 than with Tordon 101.

CONCLUSIONS

The application of ratio and regression estimators of hardwood growth in herbicide efficacy studies was demonstrated using second-year results for two species. Average control based on change is the lowest while regression-based control is the greatest. Variances, indicated by mean-squared errors, are smallest when control is based on a regression estimator and largest when based on change between pre- and post-treatment measurements. Conclusions based on treatment contrasts are not always the same for all three methods of accounting for hardwood growth in efficacy estimates.

To reduce subjectivity and minimize variances, efficacy should be based on a measure of hardwood crown dimensions. Graphs of pre- and post-treatment crown size on untreated plots should be used to observe trends in proportional variance and at the origin. A ratio approach may be suitable if the regression line passes through the origin and if the variance of post-treatment size is proportional to pretreatment size. However, a regression approach is more flexible since deviations form straight-line relationships between pre- and post-treatment size, with or without an intercept term, may be accounted for using multiple regressions or linear transformations of some nonlinear models; and proportional variances may be compensated for using weighted regressions.

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ECONOMIC RETURNS USING SULFOMETURON METHYL (OUST) FOR HERBACEOUS WEED CONTROL IN SOUTHERN PINE PLANTATIONS[1]

Rodney L. Busby[2]

Abstract.--The economics of herbaceous weed control using sulfometuron methyl (Oust) in young loblolly pine plantations was examined in this study. Numerous studies have shown that herbaceous weed control significantly influences early seedling growth, and there is some evidence that early gains have long-term impacts on stand development. The primary assumption in this study was that herbaceous weed control would accelerate stand development and thereby reduce the time it takes the trees to reach a given size.

A variety of stand conditions and management options were used in examining the economics of herbaceous weed control. Costs were estimated for each option, and land expectation values were calculated. The differences in land expectation values with and without herbaceous weed control were calculated under the assumption that control with this herbicide would accelerate the rotation age by 1, 2, or 3 years. The results show that herbaceous weed control using sulfometuron methyl (Oust) is profitable over a fairly wide range of conditions, even if the rotation age can be reduced by only 1 or 2 years.[3]

INTRODUCTION

Successful southern pine plantation management[4] requires that the site be adequately prepared for successful planting. A major problem in regenerating cutover forest lands is the presence of hardwood sprouts and herbaceous weeds that compete with the pine. Control of this undesirable vegetation is a major expense, and forest landowners are understandably concerned about how much of an investment they can afford to undertake.

Herbaceous weeds invade the site following harvest and compete with pine seedlings for moisture, light, and nutrients. Studies have shown that control of herbaceous vegetation favorably influences early seedling growth in southern pine plantations significantly.

Hardwood competition, although a major problem on many sites, is not the focus of this analysis. In this study it was assumed that hardwood competition was controlled during site preparation activities and that release from hardwood competition was not required.

A Review of the Literature

Sulfometuron methyl is effective against a broad range of broadleaf weeds and grasses. Michael (1985) found that sulfometuron methyl controlled much of the herbaceous competition; he recommends that it be applied from the pre-emergence to the post-emergence stage (when weeds become 12 to 18 inches in height).

Tiarks and Haywood (1986) show that herbaceous weed control had a greater impact than woody vegetation control or fertilization in a study in a Winn Parish, Louisiana loblolly pine (*Pinus taeda* L.) plantation. Herbaceous control

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] This study was conducted with the aid of funds provided by the National Agricultural Pesticide Impact Assessment Program (NAPIAP).

[4] In Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

resulted in increases in both average stand diameter and height.

Terry and Lowery (1986) report that herbaceous weed control results in a height growth response of 2 to 3 feet in loblolly pine after four field-growing seasons.

Baker (1973), in a study of slash pine (*Pinus elliottii* Engelm.) in the Florida sandhills, concluded that weed control increased available soil moisture and thus decreased the number of days during the growing season that trees were growing under moderate or severe soil moisture stress. He found that herbaceous weed control increased 5-year height growth, although not as much as fertilization or irrigation.

Creighton and others (1986) summarized the results of 15 studies of loblolly pine plantations, age 4 to 11 years, on sites located in four states: Arkansas(5), Mississippi(3), North Carolina(6), and Oklahoma(1). They concluded that mean individual pine tree height, diameter breast height, basal area, and total volume were greater on plots with herbaceous weed control than on the untreated plots in each study.

Nelson and others (1981) report that herbaceous control on loblolly pine sites results in dramatic pine-growth acceleration. The authors felt that it might be possible to shorten rotations by 2 to 3 years in stands with herbaceous weed control.

Nelson and others (1985) report that herbaceous weed control had a favorable impact on longleaf pine (*Pinus palustris* Mill.) growth. One year of weed control resulted in trees about 2 feet taller and 0.3 inch greater in groundline diameter than trees on plots with no weed control 4 years after planting.

Knowe and others (1985) found significant differences in 4-year total height, groundline diameter (GLD), and volumes of loblolly pines between plots with and without herbaceous weed control. They tested herbaceous weed control using either broadcast or band application for 1 and 2 years after planting. The broadcast application treated the entire site; the band application treated a 4-foot band centered around each row of planted trees. There was no difference in results between the broadcast and banded applications for the 1-year treatment. However, where herbaceous weed control lasted 2 years, broadcast treatment resulted in more growth than banded treatment. The authors suggest that the root systems of newly planted loblolly pine trees may not have expanded beyond the 4-foot area of treatment during the first year, making the control of herbaceous vegetation beyond the bands ineffective. During the second year, the broadcast treatment probably became more effective because the roots of the pine competed for water with the herbaceous weeds beyond the bands. The broadcast treatment eliminated that competition, whereas the band treatment did not.

Clason (1984) reports that herbaceous vegetation control had no detectable effect at ages 12 or 17 on thinned loblolly pine stands that were treated at age 7. His study suggests that herbaceous weed control may not be effective once the trees reach a certain size.

Zutter and others (1986) found that 1-year height growth and GLD growth were greater on plots with herbaceous weed control than on sites with high weed competition. "Medium" weed competition plots had 28 and 59 percent increases in height and GLD growth, respectively, compared to "high" weed competition plots. "Low" weed competition plots had 37 and 93 percent increases in height and GLD growth. The authors attributed the effects of herbaceous weed control on pine growth in part to differences in soil moisture and its effects on seedling water status and physiological processes.

Glover and others (1987) concluded that early herbaceous weed control significantly contributed to the growth of a 10-year-old loblolly pine stand. Diameter, height, basal area, and volume production were all enhanced by herbaceous vegetation control on poor, medium, and high quality sites.

Long-term Effects of Herbaceous Weed Control

It is essential to estimate the long-term results of herbaceous weed control on the growth and yield of the residual forest stand. As discussed above, evidence has shown that herbaceous weed control has a measurable short-term impact on the growth of a stand and there is also some evidence of long-term changes. A key question is--what form do the changes take?

There are several theories about the long-term results of early acceleration of growth. Daniels and Burkhart (1975) make the assumption that the effects of intensive culture are equivalent to a change in site index. Schmidtling (1984) found that although the effects of early intensive culture do not entirely disappear, the result is a change in the height-age curve for the site, not a movement to a higher site index.

The long-term effects of herbaceous weed control may also be measured by acceleration of the development of a stand. For example, herbaceous weed control may cause a pine stand development at age 18 that would have occurred at age 20 without treatment. Unfortunately, because rotation length data do not exist, it is impossible to know precisely how many years of acceleration are provided by herbaceous weed control.

The direct physical effects of herbaceous weed control last only a short period of time. Trees released from weed competition occupy the site faster than they would without the treatment because the trees overtop the herbaceous weeds. The fundamental productivity of the site is not altered, however.

Normally, herbaceous weed control would have the greatest impact soon after the seedlings are planted, when the roots of the seedlings and the weeds are competing in the same area. Once a tree's primary competitors become neighboring pines and other woody vegetation, herbaceous vegetation control should have only a minor impact.

Additional benefits of herbaceous weed control are an increase in seedling survival and a reduction in the risk of fire loss in the year of treatment. The additional seedling survival would reduce the planting and seedling costs; the exact amount of decrease would depend upon the pattern of seedling mortality. If a large block of seedlings died, the manager might have a major expense to replant that particular area. If mortality was expected to occur randomly, the manager could simply plant additional seedlings to compensate for the expected mortality. Although increased seedling survival can be important, it was not included in this analysis because information concerning the risk of plantation loss and seedling mortality was not available.

Decreases in the probability of loss of a plantation due to fire in the year it is treated were likewise not considered. It is difficult to quantify the probability decrease and convert that benefit into an expected value because of the lack of good information.

Objective of the Study

The objective of this study was to determine under what conditions the benefits from the treatment with sulfometuron methyl would be financially justified.

METHODS

Ideally, the best way to examine the economics of herbaceous weed control would be to access a data base that contained long-term data from a series of carefully controlled experiments conducted under a variety of conditions. With this information, the economic returns could readily be determined if prices and costs could be projected into the future. Unfortunately, such a data base does not exist, and future costs and prices are unknown. Therefore, other methods were used to conduct the analysis.

valuation Criterion

The key criterion used to evaluate the economic efficiency of herbaceous weed control was the change in land expectation value (LEV). LEV is the discounted present net value of all future benefits and costs.

Base LEVs, without weed control, were calculated on the basis of an infinite series of rotations, each rotation having the same sequence of management actions and outputs, for three productivity classes (base age 25): (1) site index 60, (2) site index 70, and (3) site index 80. The management regime consisted of site preparation, planting, and a final harvest in year 25.

Next, LEVs were calculated for the same productivity classes but for management regimes that included herbaceous weed control. The herbaceous weed control consisted of a one-time application of sulfometuron methyl in the first growing season of the plantation. The difference between the LEVs with and without herbaceous weed control was the increase in value created by using the management technique. If the increment was positive, then we concluded that the management option increases the wealth of the land owner. If the increment was negative, then the management option cost more than it returned. Finally, if the increment was equal to zero, the additional costs were just covered by additional revenue.

Because LEVs discount future revenues and costs to a current value, they are displayed as LEV(4.0), where 4.0 is the percentage rate used to discount all cash flows. Management costs and stumpage prices were assumed to increase at the same rate as inflation. All future cash flows were first adjusted to have the same buying power as 1988 dollars, then they were discounted to the present using the 4-percent discount rate. That discount rate is assumed to be the guiding rate of interest required by landowners to keep their investment in forestry.

Growth and Yield Model

The growth and yield model of Hafley and others (1982) for loblolly pine was used for all analyses. The site index values used were 60, 70, and 80 (base age 25). The number of trees planted per acre was 700. Harvest age was set at 25 years. Hardwoods were assumed not to be a significant portion of the stand at harvest age; early site preparation efforts and pine crown closure were assumed to keep the hardwood level low. Model output (table 1) consisted of estimates of sawtimber, chip-n-saw, and pulpwood volumes for each management regime and site combination. These product yields were combined with the relevant stumpage prices to obtain estimates of revenues used in the economic analysis. This paper assumes that all three products (sawtimber logs, chip-n-saw bolts, and pulpwood logs) are produced; the production of pulpwood alone from the stands would reduce the returns available from them and will not be considered here.

Table 1.--Growth and yield data used in this analysis

Site index	Volume harvested Sawtimber	 Chip-n-saw	 Pulpwood
	mbf, Scrib.	------ cords	-------
80	6.6	26.5	17.8
70	2.9	18.7	19.9
60	0.5	13.9	19.3

Stumpage Values

Stumpage prices (table 2) used in the analysis were average stumpage prices taken from a Timber

Mart South reporting district in Alabama. Average values were computed using data covering a 2-year period ending in October 1987. The prices used are conservative; as noted earlier, they were assumed to remain constant in real terms.

Table 2.--Stumpage prices used in the analysis

Product	Unit of measurement	Price
Sawtimber	mbf, Scribner	$151.16
Chip-n-saw	cords	40.01
Pulpwood	cords	19.53

Site Preparation Costs

Actual site preparation costs vary with conditions. For this analysis, it was assumed that cutover lands had a site preparation cost of $95.00/acre--the overall average site preparation cost reported by Watson and others (1987). The site preparation costs were not avoidable, and they were assumed not to vary with the amount of herbaceous weed control.

Planting and Seedling Costs

Planting costs, taken from a survey conducted by Watson and others (1987), were $33.00/acre. This was the reported overall cost of planting in the survey.

Seedling costs of $30.00/1,000 were taken from seedling prices for improved loblolly pine seedlings recently reported in Anon. (1987). Total planting and seedling costs per acre for a planting density of 700 trees per acre was $54.00.

Herbaceous Weed Control Costs

These costs depend upon treatment costs and chemical costs. Treatment costs are the costs of applying the chemical on the site. They are a function of (1) the type of treatment, (2) the type of pre-existing stand, (3) the size of the treatment area, (4) topography, and (5) the type of existing vegetation. The costs presented are for the treatment of a cutover pine stand. They represent average costs for typical conditions encountered. These representative costs were provided by a forestry consultant engaged in this type of work.

Three types of treatments were recognized in this analysis: spot, band, and broadcast. Spot treatment consists of treating the herbaceous vegetation in the area immediately surrounding a planted tree. Miller (1985) says that an area 42 inches in diameter should be treated. In this analysis it was assumed that such a treatment area would be adequate. Band treatment consists of treating a continuous band of vegetation along each planted row. In this analysis, the total band width was assumed to be 42 inches. In broadcast treatment, the entire site is treated.

Chemical costs are a function of (1) the price of the chemical, (2) the amount of chemical needed to effectively treat each acre, and (3) the type of treatment. Chemical costs were assumed to be $128.00/lb of active ingredient (a.i.). That price is a quoted one for sulfometuron methyl (Oust) in 1988. The amount actually paid may vary depending upon the size of the purchase, the amount of other business the buyer does with the seller, and the method of delivery.

The amount of chemical needed to treat each acre varies with the stage of development of the herbaceous weeds when the the acre is treated and the organic content of the soil. In this study it was assumed that 4 ounces of active ingredient per acre would be sufficient to achieve control of the herbaceous vegetation.

Finally, chemical costs depend greatly on the type of treatment. Because spot treatments cover a fixed area around each tree, the amount of chemical used is a function of that area and the number of trees planted. The chemical cost for band treatment is also a function of the area treated, so it is determined by the number of bands, their width, and total length. Since band width is fixed, the amount of chemical is a function of the number of trees planted and their spacing. Chemical costs for broadcast treatments are independent of the number of trees planted and spacing because the entire area is treated.

Table 3 lists the cost per acre of a treatment with sulfometuron methyl (Oust) for the conditions used in this analysis.

Table 3.--Chemical and treatment costs for herbaceous vegetation control[1]

Treatment type	Treatment	Chemical	Total
	------- cost per acre	-------	
Spot	$20.00	$ 4.95	$24.95
Band	20.00	14.19	34.19
Broadcast	35.00	32.00	67.00

[1] 700 trees planted, 4 oz. a.i./acre.

Miscellaneous Management Costs

Miscellaneous management costs, including the cost of burning, property taxes, and other cost items, were assumed to be $3.00/acre/year.

Analysis

Growth and yield data were combined with relevant prices and costs of management to calculate LEVs without herbaceous weed control. The effect of herbaceous weed competition control was modeled by calculating the LEVs under the assumption that the harvest volumes generated were obtained 1, 2, or 3 years earlier than they woul have been without herbaceous weed control. Thre LEVs for stands with herbaceous weed control wer obtained for each site and treatment combination. These values were then compared with values for stands without herbaceous weed control.

The purpose of the successive calculations of LEVs was to separate to some extent the estimation of total biological impact from the economic evaluation of that impact. The economic justification of herbaceous weed control will depend upon whether it takes a 1-, 2-, or 3-year shift in the rotation age to increase the LEV.

RESULTS

Table 4 presents the results of the analysis in terms of changes in LEV(4.0) for three site classes subjected to three types of treatment.

Table 4.--Economic returns from herbaceous weed control with 4 ounces a.i. of sulfometuron methyl by site index, method of treatment, and response to treatment

Site index	Treatment type	Base LEV(4.0)	Change in LEV(4.0) due to an acceleration in the rotation of--		
			1 year	2 years	3 years
80	Spot	$1,131	$48	$144	$249
70	Spot	632	15	76	142
60	Spot	292	-7	29	68
80	Band	1,131	33	128	233
70	Band	632	0	60	126
60	Band	292	-22	13	52
80	Broadcast	1,131	-21	73	177
70	Broadcast	632	-54	5	69
60	Broadcast	292	-76	-42	-4

CONCLUSIONS

The literature reviewed shows that herbaceous vegetation control produces a short-term increase in the growth of pine stands. Unfortunately, there are no rotation-length studies to show the long-term effects. There is some evidence to suggest, however, that short-term changes in growth can have long-term effects. The assumption used in this analysis was that the long-term effect may be measured by an acceleration of the development of the stand. For example, if a particular stand were ready for harvest in 25 years without herbaceous weed control, the same stand could be developed to that level in only 24, 23, or even 22 years with herbaceous weed control.

The economic efficiency of herbaceous weed control depends upon whether the LEV can be increased, remains the same, or declines when the practice is used. Simulations were performed to determine whether herbaceous weed control is profitable under typical conditions.

If herbaceous weed control decreases the rotation age by even 1 year, the technique is economically efficient for both spot and band treatments on site index 70 and 80 lands. However, it is not efficient on site index 60 lands. A 1-year acceleration of stand development is not sufficient to improve the LEV for broadcast treatments on any site because of the very high treatment and chemical costs.

A 2-year acceleration in the development of a stand would make spot treatments efficient on all site classes. The increases in LEV(4.0) are $29, $76, and $144 per acre for site indices 60, 70, or 80, respectively.

If herbaceous weed control decreases the rotation age by 3 years, the technique is efficient for all treatment types on all classes of site, except for broadcast treatments on site index 60 lands. The change in LEV(4.0) is only modestly negative, however. If broadcast treatment costs could be reduced from the amounts reported above by just a small amount, broadcast treatment would be profitable also.

The magnitude of improvement in stand growth is an important factor in analyzing the results. The simulation showed that, in some circumstances, the LEVs would be increased quite dramatically if herbaceous weed control were used. The rewards are high enough for the technique to be seriously considered by all plantation owners.

Forest managers must make their own decisions about the extent to which herbaceous weed control accelerates the development of their plantations. Scientists simply have not been studying the problem long enough to come up with definitive answers as to the exact magnitude of the effect for individual stands. The results presented here show that the technique is profitable over a fairly wide range of conditions, even if the rotation age can be reduced by 1 or 2 years.

Prudent forest landowners should be convinced that increasing the amount of chemical used to treat each acre is justified before they decide to use broadcast treatments rather than spot or band treatments. They should also be convinced that the application rate chosen is sufficient to accomplish the task, but is not excessive. Finally, they should limit investments in this practice to sites that are good enough so that the increase in the LEV from a reduction in the rotation age is significant.

In summary, the evidence presented here is strong enough to say that herbaceous weed control using sulfometuron methyl (Oust) is economically efficient even under conservative assumptions about the effects of the technique. Although forest land owners should exercise caution, given the sizes of growth increments shown in the literature and the possible greater economic returns shown in this analysis, investment in herbaceous weed control seems to be a prudent silvicultural option.

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ECONOMICS OF HERBACEOUS AND WOODY WEED CONTROL IN LOBLOLLY PINE PLANTATIONS[1]

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Abstract.--The history of weed control in planted pines has been one of fire, mechanical means and neglect. Many marginal row-crop acres are converting to planted pines. Regeneration efforts on cut-over forest acres lag behind harvested tree acres. Weed competition on converted and regenerated acres is high. Presented results model dollar linkages between weed competition and wood growth as Net Present Value in planted loblolly pines.

INTRODUCTION

History of Weed Control in Pines

A Forest Service researcher, Dr. James H. Miller, has suggested that weed control must have been one of the first cultural practices of early people. As they changed from foraging to gathering, humans began to care for the wild plants that provided their food. Even before they learned other cultural practices, they must have realized that weed plants growing too close interfered with the food producing plants. So as agriculture developed we learned that weed control can increase yields, improve quality and facilitate harvesting.

Early examples of weed control are most often associated with mechanical means. In pine tree culture this usually includes some type of bulldozer operation. The work is slow and often expensive, but has been the most dependable means available to control weeds in pines.

Attempts to find selective herbicides suitable for economical release of pines has been a difficult task. Although most herbicides presently used have only recently been developed, research began many years ago. Sodium arsenite, one of the first chemicals developed, was tried in the '30's.

Herbaceous weed control in newly planted pines is the most recently developed use of herbicides. Selective herbicides that have shown potential for this purpose have increasingly been tried in the last ten years. Only recently has it been proven that herbaceous as well as woody competition in young pines effects future growth and volume.

Importance of Pines in Georgia

Georgia is currently considered the national leader in forestry. Forestry is the State's leading industry, adding over eight billion dollars annually to the economy and employing over 80,000 workers. Pine trees account for over three-fourths of this value.

Supply and Demand for Wood

Studies indicate that the demand for pine timber will increase and will out strip pine growth. This will maintain or increase stumpage prices well into the 21st century. However, to maintain a healthy forest economy we must develop an adequate supply of timber. Fortunately, many of the opportunities to increase the timber inventory can be profitable investments for landowners. For example, returns from the low-cost conversion of marginal or highly erodible lands into pines, can exceed inflation by ten percent or more.

Importance of Weed Control

Regeneration and forest management investments can often be assured or made more profitable by some form of vegetation management. Herbaceous weed control in newly planted pines can help assure survival and increase pine growth. Woody survival and increase pine growth. Woody competition control is usually necessary before planting pines on cut-over sites. On sites where less intensive or no site preparation is done prior to planting, woody release of pines can increase growth several times.

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METHODS OF ANALYSIS

Data and Calculations

The calculations done in this paper are based on earlier research to show the loss in pine wood growth due to different levels of herbaceous and woody weed competition. Loss in wood growth with different levels of weed competition is expressed as changes in Net Present Value (NPV) per acre. Simply put, NPV is the value of the investment after the effects of interest and inflation have been taken out. A NPV less than $0.00 means that less than 8% interest was earned with that example. And, a NPV greater than $0.00 means that more than 8% interest wase earned on that example.

Research on the biological effects of herbaceous weed competition on pine growth is not as complete and documented as would be desirable. However, the results from earlier research have been extrapolated for use here. This is an effort to project beyond the range of values known with certainty to provide answers to current economic problems where no better answers exist. In that sense, table results for levels of herbaceous weed competition in oldfield loblolly pine plantations are presented as best estimates, given the availablility of underlying research. Assumptions were used from Creighton, et. al 1986, Clason, and Bacon and Zedaker 1987. From these earlier works a delay in final harvest was assumed for increasing levels of herbaceous weed competition. Light weed competition was modeled to delay harvest two years, medium four years, and severe six years. Hepp's TVA forestry investment model was then used to calculate the effects of delayed harvest on measures of NPV. This was accomplished by reducing the site index and increasing rotation length to keep wood flow constant over a longer time period.

Research on the effects of woody weed competition on pine tree growth is well known and documented. Earlier research results by Burkhart and Sprinz 1984 and Hafley provided measures of decreased woodflow for increasing levels of woody weed competition. These reductions were then calculated as changes in NPV by use of Hepp's TVA Yieldplus model.

Assumptions

Several assumptions necessary to clarif how tree growth was simulated follow:

1) Tree species: Loblolly pine is use under two situations oldfield and cut-ove site plantations, 650 trees per acre, a the end of the first growing season.
2) Land productivity: Low, medium and hig productivity land was simulated by site indexs of 68/50, 80/60 and 93/70 feet a 50/25 years respectively.[1]
3) Cutting cycle: For the 20 and 25 yea rotations a thinning was done at 15 years Thinnings were at 15 and 22 years for th 30 year rotation. Residual basal areas o 70, 80 and 90 square feet, per acre, wer left after thinnings for the low, mediu and high productivity sites respectively.
4) Prices were different in the thre regions of the state as shown below. Prices used were fo Region 3. A real price inflation of tw percent was used.

Region 1-North

Products	$	DBM/[2]
Pulpwood (cord)	10.75	5-11
Chip-N-Saw (cord)	-----------	
Sawtimber (MBG[3])	150.00	12-17
Big Sawtimber (MBF)	156.00	18-36

Region 2-Piedmont

Pulpwood (cord)	16.00	5-9
Chip-N-Saw (cord)	40.00	10-12
Sawtimber (MBG[3])	160.00	13-19
Big Sawtimber (MBF)	175.00	20-36

Region 3-Coastal

Pulpwood (cord)	24.00	5-9
Chip-N-Saw (cord)	52.50	10-12
Sawtimber (MBG[3])	170.00	13-19
Big Sawtimber (MBF)	185.00	20-36

5) Taxes, inflation and other costs: Provisions of The 1986 Tax Reform Act wer incorporated into the tax affects.
- Marginal tax rate was 28% (for a average investor).
- No capital gains treatment, eighty-fou month amorization and 10% investment credi on reforestation costs (you can charge of

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[1] Height of dominant trees at age 50 and 2 years.
[2] Diameter Breast Height.
[3] Thousand Board Feet, Scribner rule.

reforestation costs over an 8 year period up to a $10,000 reforestation expense per year).

- A real price inflation of 3%, and a discount rate of 8% before taxes was used (8% is the assumed long run opportunity cost of using owned capital).
- Planting costs were $50/A for oldfield and $150 for cut-over sites (including seedlings and planting expenses).
- Property taxes were excluded.
- A management expense of $2 per year was charged and inflated at 3%.
- A control burn was started at year 14, repeated every three years, for $5 per acre and inflated at 3%.

6) Computer analysis was done using personal computer programs designed to simulate forestry scenarios by Hepp, Hafley, and Burkhart.

USING THE TABLES

The purpose of the following tables is to help landowners determine how much they can afford to spend on weed control in pine plantations. Tables 1 and 2 show the maximum dollars available to control weed competition under the different production scenarios, at different levels of competition. Table 1 is for oldfield loblolly pine plantations in Georgia. Table 2 is for cut-over site, loblolly pine plantations in Georgia. The dollar amounts used in this paper are expressed in NPV per acre.

To use tables 1 and 2 proceed as follows:

Herbaceous Weed Example

Assume you need to know how much you could afford to spend to control herbaceous weed competition in an oldfield loblolly pine plantation during the first year of the rotation. (Herbaceous weeds are all broadleaves and grasses that grow annually, and do the most damage during the first year or so of tree growth.) Say you are located in the Coastal Plain area of Georgia and your land has an average site index of 80/60. (This means that the height of the dominant trees will be 80 feet when the trees are 50 years old or 60 feet when the trees are 25 years old.) You plan on growing a 25 year rotation of trees. Your field has a severe weed problem. Go to table 1, herbaceous weed competition, Coastal Plains and Atlantic Coast Flatwoods. Then, look at the middle row, site index 80/60 and 25 year rotation. Go across to the right hand column under severe. The answer is that weed competition will be costing you about $63 per acre, in today's dollars (present value). If you do nothing to control weed competition in this field, you could expect to loose $63 worth of wood growth over the 25 year rotation. The problem now becomes to control the severe weed competition for less than the amount of wood loss. For example, if you can control the weeds for $30 per acre, you could expect to increase wood flow by $63. Your increased profits, above doing nothing, would be $63 - $30 = $33 per acre. The maximum amount that you could expect to spend controlling a severe level of weed competition would still be $63 in this example.

Look at table 1 and notice the trends. More money can be spent to control weeds on higher site index land and where longer rotations are grown. Also, more money is available to control weeds nearer the coast where timber markets are better.

Woody Weed Example

Assume in this example that you are located in the Coastal Plains area of Georgia. Let's say that you have a field that has had all the trees harvested (cut-over site) and now you want to plant a loblolly pine plantation. Assume that your land has a medium site index of 80/60 (This means that the average height of the dominant and co-dominant trees will be 80 feet when the trees are 50 nyears old or 60 feet when the trees are 25 years old.) You want to grow trees for a 25 year rotation. Also, from what you saw of the hardwood competition in the trees just harvested from this field, you figure the basal area in hardwoods will be about 40% in the new pine plantation that you are planning to plant. (This means that as the planted pines and hardwood sprouts grow together, in the new stand, pines will be 60% of the growth and hardwood competition will be 40%.) So, you can see that competing hardwoods will rob you of pine tree growth and therefore, profits.

Your job now becomes to calculate approximately how much you can afford to spend to control the competing hardwoods in your cut-over loblolly pine plantation during its first few years of growth. (Hardwoods should be controlled early in the rotation before pine growth is reduced later.) Go to table 2, woody weed competition, Coastal Plains Georgia. Look across the row labeled site index 80/60 and 25 year rotation to the column under 40%. The answer is that this level of hardwood competition will likely be costing you $159 worth of lost wood growth if you do nothing to control weed competition. The hardwood competition should be controlled for $159 per acre, or less. For each dollar less than $159 that you can control the hardwoods for, you will earn an extra dollar of profit over doing nothing.

Look at table 2 and notice the trends. More money can be spent to control weeds on higher site index land and where longer rotations are grown. Also, more money is available to control woody weeds nearer the coast where wood product prices are higher.

CONCLUSIONS

Control of both herbaceous and woody weeds in loblolly pine plantations can increase profits. However, there is a limit to the growth response that trees will make when weed competition is removed. Let's discuss the implications for economics of herbaceous weed control on oldfield sites first. Then, we can go over woody weed economics on cut-over sites.

Herbaceous Weeds

Most of the damage done by grass and broadleaf weeds in planted pines is done in the first year of the pine rotation. After that, trees are generally above the weeds and better able to compete for growing space. So, these weeds should be controlled early. Please note from Table 1 that the amount of money that can be profitably spent for herbaceous weed control varies a great deal according to conditions. Match your particular conditions to the table, row and column that most nearly match. Remember, the object is to control the weed problem for less money than is listed in the table. Then, your profits will increase to equal the difference between the table amount and the amount you spend on weed control. Also, note that herbaceous weeds do not generally cause as much economic losses as woody weed competition in planted pines. This means that generally, you cannot afford to spend as much money per acre controlling herbaceous weeds as you can on woody weeds.

Hardwood Weeds

Most of the pine growth loss caused by competing hardwood weeds in planted pines is done later in the tree rotation. The competition between pines and hardwoods usually becomes more evident somewhere between years 10 and 15 in the rotation. However, economic damage actually begins much earlier in the tree rotation. Also, if hardwoods are controlled during the first couple of years of pine growth, the job is easier and less expensive. As wit herbaceous weed control, please note fro table 2 that the amount of money that ca be profitably spent for woody weed contro varies a great deal according t conditions. Match your particula conditions to the table, row and colum that most nearly match. Remember, th object is to control the weed problem fo less money than is listed in the table Then, your profits will increase to equa the difference between the table amount an the amount you spend on weed control Also, note that woody weeds generally caus much more economic losses per acre tha herbaceous weed competition in plante pines. This means that you can generall afford to spend more money per acr controlling woody weeds than you can controlling herbaceous weeds.

Table 1.--Maximum dollars per acre for weed control in year one, in **Oldfield Loblolly Pine Plantations**, by site index, year of harvest and level of **Herbaceous Weed Competition**, Georgia, 1988, (8.0% discount rate)

Site[1] Index[2]	Year	Level of Weed Competition		
		Light	Moderate	Severe
Coastal Plain and Atlantic Coast Flatwoods				
68/50	20	2.68	3.01	5.36
	25	4.37	4.92	8.74
	30	6.68	7.51	13.36
80/60	20	6.60	7.42	13.20
	25	10.19	11.47	20.39
	30	15.10	16.99	30.20
93/70	20	11.66	13.12	23.32
	25	18.83	21.19	37.66
	30	26.18	29.46	52.37
Piedmont				
68/50	20	6.92	7.79	13.84
	25	10.57	11.89	21.13
	30	15.09	16.98	30.19
80/60	20	14.10	15.86	28.19
	25	20.94	23.56	41.88
	30	27.62	31.07	55.24
93/70	20	23.93	26.92	47.86
	25	34.25	38.53	68.50
	30	42.46	47.77	84.92
Mountains and Applachian Valleys and Ridges				
68/50	20	12.76	14.36	25.52
	25	17.67	19.88	35.34
	30	23.26	26.16	46.52
80/60	20	22.97	25.84	45.94
	25	31.62	35.57	63.23
	30	39.32	44.23	78.63
93/70	20	36.42	40.98	72.84
	25	48.83	54.94	97.66
	30	57.56	64.76	115.13

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[1] Height of dominant trees, 50 and 25 year basis.

[2] Length of tree rotation in years.

Table 2.--Maximum dollars per acre for weed control in year one, in **Cut-over Site Loblolly Pine Plantations**, by site index, year of harvest and level of **Woody Weed Competition**, Georgia, 1988, (8.0% discount rate).

Site[1] Index[2]	Year	Total Basal Area In Hardwood		
		20%	40%	60%
Coastal Plains and Atlantic Coast Flatwoods				
68/50	20	18.92	22.37	38.10
	25	25.84	27.98	45.22
	30	35.80	41.98	59.11
80/60	20	28.68	32.27	53.27
	25	4.29	46.22	71.93
	30	70.50	82.45	109.55
93/70	20	46.70	47.38	76.04
	25	100.84	66.60	99.66
	30	149.39	126.92	163.31
Piedmont				
68/50	20	26.70	36.17	59.58
	25	74.76	60.94	87.95
	30	68.22	68.98	99.69
80/60	20	42.70	58.07	89.32
	25	112.94	117.34	160.57
	30	115.10	121.17	171.84
93/70	20	55.47	107.67	151.77
	25	168.94	170.00	235.50
	30	200.43	171.75	242.63
Mtns and Appalachian Valleys and Ridges				
68/50	20	40.51	53.36	88.47
	25	99.77	85.38	125.48
	30	93.19	96.68	141.12
80/60	20	64.75	83.27	130.15
	25	149.15	158.50	221.79
	30	151.17	163.54	235.61
93/70	20	83.03	149.89	215.59
	25	216.79	226.22	320.66
	30	252.41	223.08	322.45

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[1] Height of dominant trees, 50 and 25 year basis.

[2] Length of tree rotation in years.

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AN ECONOMIC APPROACH TO EVALUATING TIMBER MANAGEMENT RESEARCH[1]

Lawrence D. Teeter and Y. Star Huang[2]

Abstract -- This study developed an economic model to evaluate timber management research programs, and evaluated the South's pine plantation herbaceous weed control research effort. The model was determined to be a useful one, and based on the analysis, it is anticipated that herbaceous weed control research will yield significant net economic benefits.

INTRODUCTION

The USDA Forest Service (1982) projects that the South will supply at least one-half of the Nation's timber products in the next few decades. There are approximately 181 million acres of timberland in the South, of which only 12 percent are pine plantations and 22 percent are natural pine forests (USDA Forest Service 1986). In order to fulfill the goal of expanding southern softwood timber supplies, the South's timberland must be managed more intensively with a focus on increasing pine regeneration and productivity.

Timber management research may play a key role in enhancing current levels of pine productivity and ensuring the continued long-term viability of forestry as a competitive economic activity. Currently, however, adequate funds are not available to support all of the research programs that foresters and researchers would like to develop. Research administrators are faced with the problem of assessing the potential importance (value) of proposed research programs and allocating scarce research resources based on those assessments.

Research evaluation is a study of research activities themselves. A number of evaluation approaches have been well developed in agricultural research since the 1950s (Norton and Davis 1981). Forestry research evaluation began formally in the mid-1960s with "Planning, Programming and Budgeting" which was the Johnson Administration's effort to allocate the Nation's resources more efficiently (Fedkiw 1985). Although there exists a variety of literature relating directly to the procedures of forestry research evaluation (e.g., Hyde 1985, Fox 1986, Jakes and Leatherberry 1986), no criteria can be found for evaluating potential impacts of ongoing or proposed research projects.

Economic evaluations of past forestry research efforts (*ex post* evaluations) have focused on forest products development with only a few exceptions. Examples include Bengston (1983, 1984), Bare and Loveless (1985), Haygreen et al. (1986), and Seldon (1987), among others. However, Jakes and Bengston (1987) pointed out that making decisions on current or future research programs using studies of past efforts may not be justified. The primary objective of this study was to identify an *ex ante* model that could be used to evaluate proposed or ongoing forest management research.

MODELS

An *ex ante* benefit cost model first presented by Araji et al. (1978) was adapted for this study. According to this model, an evaluation must compare the benefits ascribed to research with the costs of both the research itself and extension activities required to transfer new management technology to potential users. The assumption implicit in this model is that an economic benefit cannot be gained from a technological innovation unless it is adopted by forest managers.

The model is composed of several key relationships:

$$RB = TB - C_{re} - C_{ad} \qquad [1]$$

Where:

RB = Real net benefits of research and extension (R&E) investments;

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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TB = Total gross benefits of R&E investments;

C_{re} = Agency R&E expenditures;

C_{ad} = Costs of adopting technology.

Agency costs include all resources allocated to research and extension, and any additional expenses required to develop and maintain the new technology over a period of time. Adoption costs may include extra environmental considerations, security liabilities and other additional management or administration expenditures associated with implementing the new forest management technology.

$$TB = \sum_{t=0}^{n} NB_t * P(S_{t'} \cap T_t) \qquad [2]$$

Where:

TB = Total gross benefits of R&E investments;

NB_t = The potential net economic benefits of applying the technique in year t

$P(S_{t'})$ = Probability of research success in year t';

$P(T_t)$ = Probability of technology adoption in year t where t equals t'+ the lag between research success and technology adoption in years.

Huang (1988) modified this model and illustrated its applicability by evaluating the program of pine plantation herbaceous weed control (HWC) research in the South. To develop information required for implementing the model, he proposed two methods of assessing the economic benefit of a forest management innovation designed to enhance growth: 1) the volume increase (VI) model and 2) the shorter rotation (SR) model.

The VI model assumes that managers will manage treated stands according to the same rotation schedule as untreated stands, and expect to obtain some volume advantage at final harvest for the treated stands. Equation 3 shows how the final harvest benefit is assessed according to the VI model:

$$BF_t = A_t \left[\frac{P_{t+r} * dV - C_{t+a} * (1+i)^{r-a}}{(1+i)^{r} - 1} \right] * (1+i)^{T} \qquad [3]$$

Where:

BF_t = Potential present net benefits from final harvest in year t due to HWC treatment (in base year values);

A = Potential area for adopting HWC techniques;

P = Stumpage price per acre;

T = Base year (1988) minus adoption year (t);

r = Harvesting age in years;

a = Plantation age when applying HWC treatment;

dV = Expected changes in pine volume per acre;

C = Costs of HWC treatment per acre;

i = Discount rate.

The alternative approach to assessing benefits (the SR model) acknowledges that treated stands can produce specified timber volumes earlier than nontreated stands. If the goal of management is to produce timber volumes on treated plantations equivalent to the volumes achievable on untreated plantations, treated stands can be managed on a shorter rotation. This shorter rotation will accordingly reduce the discounting period and increase the present value of the plantation. Using equation [1] to calculate the land expectation values for both treated and untreated pine plantations, differences in final harvest year "r" will produce different LEV's. The difference between these LEV's, attributable to the earlier harvest of the treated stands, can be viewed as the per acre net benefit of the management innovation (treatment). Equation [3] can be reorganized to yield the shorter rotation (SR) model:

$$BF_t = A_t \left[\left[\frac{P_{t+r} * V - C_{t+a} * (1+i)^{r'-a}}{(1+i)^{r'} - 1} \right] * (1+i)^{T} - \left[\frac{P_{t+r} * V}{(1+i)^{r'} - 1} \right] * (1+i)^{T} \right] \qquad [4]$$

where the first term on the right-hand side of equation [4] represents the LEV of treated plantations and the second term represents the LEV of untreated plantations, both at year "t". The value "V" is pine volume available for final harvest and is variable according to different site qualities, pine species, and harvest schedules. The symbol r' is a rotation age shorter than r that results from HWC treatments.

Thinning benefits are evaluated identically for both the VI and SR models using an LEV-type formulation. Treated stands are assumed to reach a level of basal area that demands thinning at an earlier age than untreated stands. The same thinning strategies are assumed to apply (i.e. the same volume is removed in treated and untreated stands) and therefore, the benefit is simply a function of the earlier harvest (shorter discounting period) and the product prices available in each thinning year.

DATA

The case study evaluation was concerned with assessing the economic impacts of the HWC research program over a 20-year period from 1979-1998. Data from a large variety of primary and secondary sources were used to obtain estimates of the parameters required by the research evaluation model. Because obtaining data on the management of non-industrial private lands was considered too difficult, this analysis focused on the impact the research would have on industry managed lands. For example, **A** in equations 3 and 4 is an estimate of the potential annual area available for (HWC) treatment. For the purposes of this study, this translates into the number of acres regenerated to pines by industry in a given year. This acreage was available from historical records for the years prior to 1988, and was projected on the basis of information reported by the U.S. Forest Service (1986) for the period 1988-1998 (Figure 1).

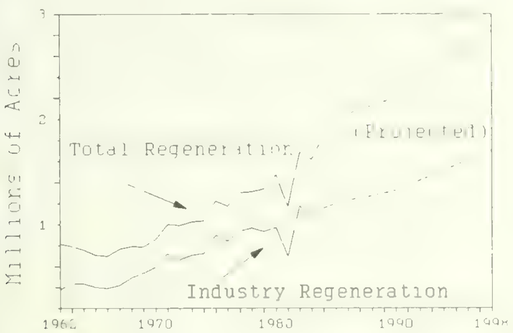

Figure 1. Historical and projected pine regeneration acreage (total and industry) -- 1962-1998.

To determine the region-wide potential pine growth effects of HWC treatments we used experimental data indicating the effects observed on research plots, estimates of the site productivity of regenerated lands, estimates of the proportion of each pine species actually planted, and reports of the anticipated future management regimes for the treated stands. Based on a collection of U.S. Forest Service resource survey reports for each state in the South, we determined the productivity class distribution of the region's 180 million acres of timberland (Figure 2).

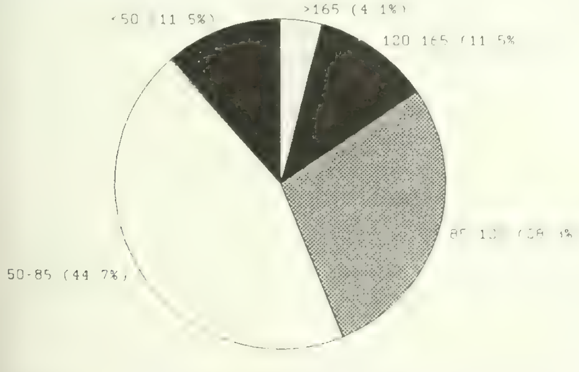

Figure 2. Timberland area in the South by site class (cubic feet/acre/year production potential).

To determine the distribution of pine types planted during the analysis period, industry representatives were surveyed (see Huang 1988). They reported the number of acres of each pine species planted for each year from 1979-1988, and projected future plantings for the years 1989-1998. Figure 3 shows the species planted in 1988.

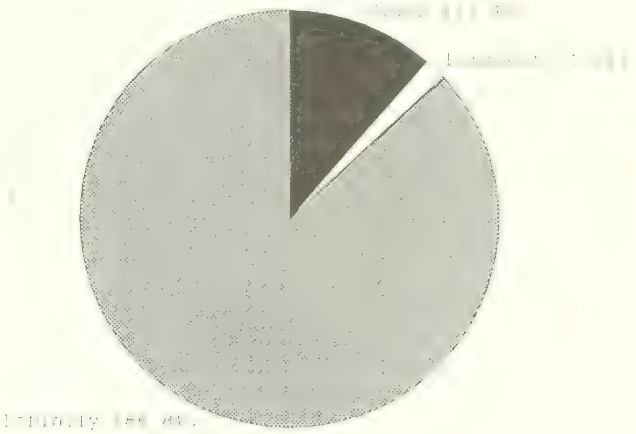

Figure 3. In 1988, three pine species were used to regenerate industry lands in the South according to a survey of industry managers (see Huang 1988). regeneration efforts in 1988.

Finally, in addition to the species planted in any particular year and the productivity of the lands they are planted on[3], it was necessary to determine how those lands are (will be) managed in order to determine the potential effects of adopting the new management technology (HWC). Harvest schedules for regenerated lands were obtained from the survey of industry managers (see above) for stands regenerated each year of the analysis period. Figure 4 indicates in a summary way how management has changed over the two decade period.

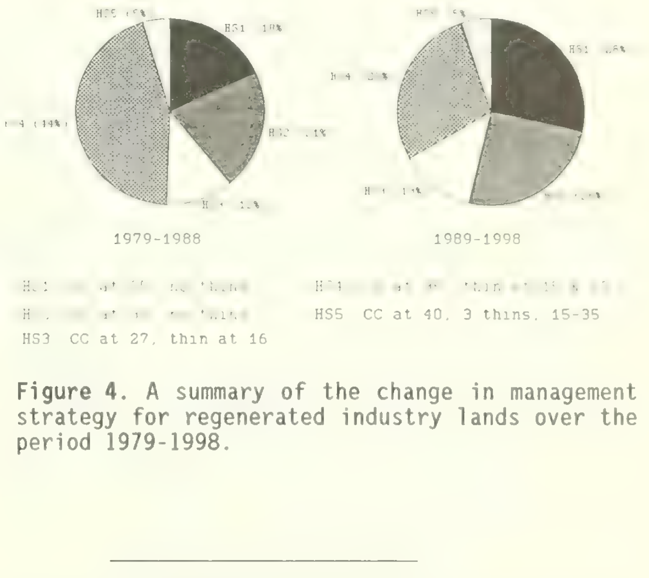

Figure 4. A summary of the change in management strategy for regenerated industry lands over the period 1979-1998.

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[3] It is assumed that industry manages lands with productivity equal to the overall distribution of productivity for timberlands in the South.

These categories of information (regeneration acres, acres by site class, and the harvest schedules of the regenerated acres) were necessary to determine **A** in equations 3 and 4 as discussed above (for a site class and future management regime). The growth impacts ascribed to HWC were determined analytically using research data (Burkhart et al. 1987) and growth and yield simulators. The data describe the growth effects attributable to HWC on three sites for 10 and 11 year old stands of loblolly pine (Pinus taeda L.). HDWD, a growth and yield simulator developed by Burkhart and Sprinz (1984), was used to determine the impacts of HWC in terms of its effects on the rate of stand development. First the model was calibrated so that it would generate stand characteristics similar to those observed in the untreated (NHWC) stands at the measurement age. Then, the stands were grown some additional period of time until stand attributes resembling those observed in the HWC treated stands were obtained. The additional period of time was considered to be the growth advantage attributable to HWC.

Figure 5 illustrates how this growth advantage was used to outline a pine yield curve for HWC treated stands on the Dubberly (Georgia) site. It was assumed that the growth advantage determined to exist at age 10 or 11 (depending on the age of the stand when the data were collected) would persist throughout the remainder of the rotation. So, for example, if an 11-year old HWC stand at Dubberly had the attributes of a 14-year old NHWC stand, at age 22 an HWC stand would have the attributes of a 25-year old NHWC stand.

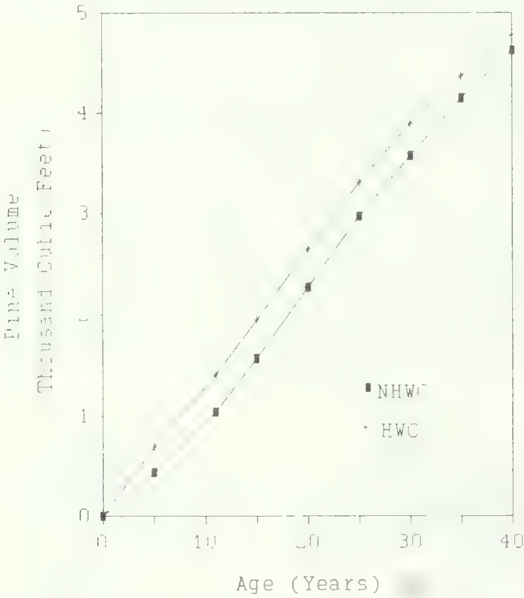

Figure 5. Simulated pine yield curves for HWC and NHWC pine plantations at the Dubberly site. The age advantage was determined to be three years at this site.

Over the test sites analyzed, we determined that HWC treatments result in a 3-year (average) growth advantage. This information was then used in conjunction with another simulator, YieldPlus (Hepp 1987), to simulate the thinning and final harvest benefits of HWC treatments for the various combinations of species, site productivity classes, and harvest schedules determined above.

To determine the net economic benefits associated with these growth gains, several items of information are still required. First, estimates of future stumpage prices and per acre application costs are necessary to determine the net revenue advantage associated with HWC treatments. Second, the costs of HWC research and extension efforts are necessary if a cost/benefit evaluation of the research program is desired. Finally, estimates of the probability of future research success and technology adoption are necessary to determine the potential contributions of future efforts in the research program (equation 2).

Future revenues were estimated using three sets of future price projections (Figure 6). The highest level of prices represents the base level situation as described by Haynes and Adams (1985) and assumes no significant departures from current approaches to pine plantation management. The middle level of prices assumes a significant increase in the level of management intensity on industry owned lands (which would increase the supply of stumpage and, other things being equal, would tend to lower its price). The lowest level of prices examined simply assumes that prices will not increase (in real terms) above their 1988 levels. Based on the results of a survey (Huang 1988) of herbicide applicators, costs were held constant at $27/ac from 1979-1988, and were increased 2.5% annually from 1989-1998.

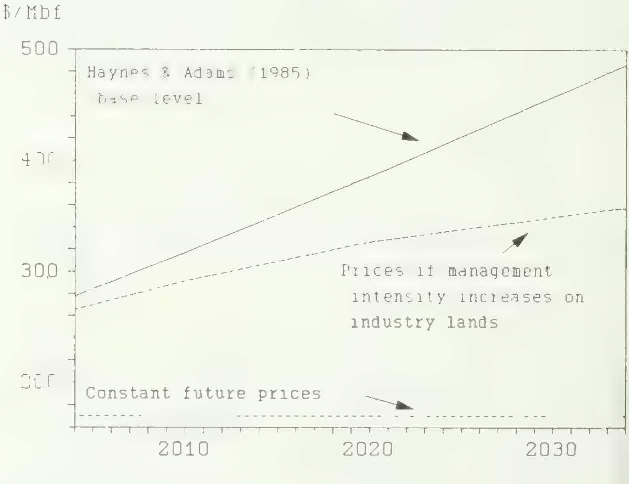

Figure 6. Three sets of stumpage price projections -- 2004-2034.

Public and private groups conducting HWC research were surveyed to determine historical and projected expenditures on HWC research and extension activities. Figure 7 illustrates how those costs have increased over the past decade and how they are expected to stabilize over the next ten years.

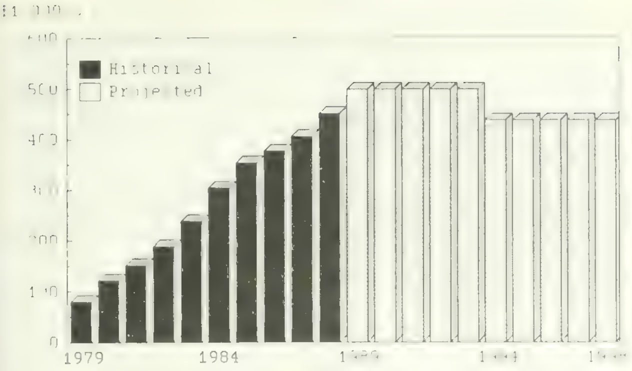

Figure 7. Historical and projected herbaceous weed control research and extension expenditures.

Probabilities of research success and technology adoption were obtained by surveying research groups and industry land managers. A research success was defined as a project yielding applicable results that can readily be adopted by forest managers. Figure 8 indicates how researchers and land managers feel about their prospects for future research success and future use of this technology, respectively. Note that actual future adoption rates are affected by the rates of future research success (equation 2). Using simple linear regression techniques and the data obtained from the survey, the lag between research success and technology adoption was determined to be 3 years.

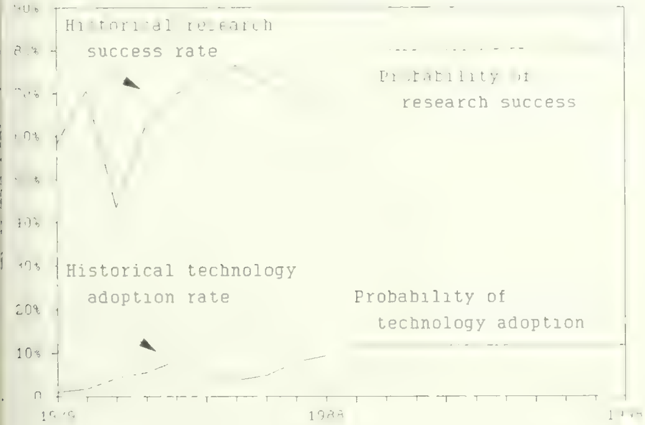

Figure 8. Historical and future (probabilities) rates of HWC research success and technology adoption based on surveys of researchers and land managers (see Huang 1988).

RESULTS/DISCUSSION

Benefit/cost ratios and real net benefit estimates that resulted from our base case analysis indicate that the HWC research effort will produce significant economic benefits. The B/C ratios range from about 18 to slightly over 21, depending on the model used to establish the benefit estimates (equations 3 & 4). To determine the effect of our basic assumptions on these results, we conducted a series of sensitivity tests. The assumptions tested include:

1. Future prices will follow the base level projections of Haynes and Adams (1985).
2. Herbicide application costs average $27/ac.
3. HWC provides a 3-year growth advantage.
4. The appropriate discount is 7%.

Base case results were effected most by a reduction in the growth advantage ascribed to HWC. When the advantage was reduced from 3 years to 2 years, the B/C ratio fell by approximately 60%. The resulting B/C ratio (~10) still indicates that past and projected investments in HWC research will produce significant net benefits.

One major problem in forestry research evaluation is a lack of applicable approaches to conduct evaluations of research yet to be initiated or completed (Jakes and Risbrudt 1988). This study developed a model from common net present value (NPV) and land expectation value (LEV) concepts. Merits of the model are its simplicity and flexibility. Therefore, it is hoped the model can be used more conventionally to provide information for future research resource allocation decisions.

Further efforts are needed to deal with the potential problems concerning externalities and secondary effects associated with the development and application of a new technology. This effort investigated the economic impacts of HWC research only from the viewpoint of timber production. Other non-timber effects and non-economic impacts may significantly affect technology adoption and/or final research investment decisions.

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EARLY RELEASE OF BOTTOMLAND OAK ENRICHMENT PLANTINGS APPEARS PROMISING IN SOUTH CAROLINA[1]

Larry E. Nix[2]

Abstract.--After six growing seasons, one-year-old, bare root, cherrybark oak seedlings planted on a clearcut, windrowed first bottom site in South Carolina exhibit differences in response to early competition control methods. Cardboard mulch sheets and 2 percent glyphosate spring and fall spraying, all resulted in significantly greater seedling growth and survival than that of untreated control plots. Release treatments resulted in a mean sapling height and basal diameter of 8 ft and 1 in, respectively, whereas untreated saplings averaged 6 ft tall and 0.6 in basal diameter. Survival was 95 percent for the two herbicide treatments, 88 percent for the mulch sheets, and 75 percent for untreated controls. Dominant woody competition averaged 13 ft height and 4,500 stems per acre, but nearly 50 percent of the released oaks are free to grow. These early treatments appear promising where enrichment plantings are the objective, rather than plantations.[3]

INTRODUCTION

The beautiful and productive bottomland forests of the South have long been a valuable source of quality hardwood lumber, veneer and wildlife habitat. Among the more valuable components of these bottomland hardwoods are the tall straight, well-formed oaks, such as southern red (*Quercus falcata*), Shumard (*Q. shumardii*), cherrybark (*Q. falcata* var. *pagodifolia*), and Nutall (*Q. nuttalli*). However, past cutting practices, indiscriminant cattle grazing, and lack of adequate attention to regeneration needs have resulted in an apparent diminishing of the quality oak component in many bottomland stands (Johnson 1979). In many instances, fertile, high quality oak sites have regenerated to light-seeded pioneer type species or persistent, vigorous stump sprouters, such as elm (*Ulmus americana*), ash (*Fraxinus pennsylvanica*), sugarberry (*Celtis laevigata*), sycamore (*Platanus occidentalis*), cottonwood (*Populus deltoides*), box elder (*Acer negundo*), and sweetgum (*Liquidambar styraciflua*). Loss of the oaks has occurred after harvesting many stands, even when their overstories contained an appreciable oak component. Lack of establishment of advanced oak reproduction appears to be a major cause of the loss of the oak component in many mixed hardwood stands, both uplands and bottomlands (Hannah 1987, Johnson 1979, Johnson and Shropshire 1983).

In a number of bottomland stands in the South that are currently being harvested, the oak overstory component is small or so negligible that adequate natural reproduction of oaks in the new stand is unlikely to be satisfactory, regardless of the regeneration method used, even on sites highly suitable for managing quality oaks. On such sites improving the species composition in favor of quality oaks through artificial means, such as planting or direct seeding, could prove to be a valuable alternative to accepting bottomland stands with little or no quality oak component (Johnson and Shropshire 1983, Johnson and Krinard 1987, Kennedy and Johnson 1984).

One of the major problems with planting or direct seeding oaks is the slow early growth of the seedlings, which are quickly overtopped by the seedlings of fast-growing pioneer species or residual stump sprouts, especially in the more open light conditions that favor the rapid early growth of the intolerant, quality oaks. One solution to this competition problem is, of course, the shelterwood regeneration method with underplanting or direct seeding of oaks, but both mid-story and understory competition can be fierce in such an environment, so that reduction of competition may be essential with most regeneration methods (Hannah 1987, Johnson and Shropshire 1983).

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Associate Professor, Department of Forestry, Clemson University, Clemson, SC 29634-1003.

[3] The author would like to express deepest appreciation for the contributions made by the following individuals in the establishment and completion of this study: Mr. Edward Drayton of Sonoco Products Company, Hartsville, S.C.; Mr. Robert Odebralski, former graduate student; Mr. Knight Cox and Mr. Mark Augspurger, former research associates.

This paper reports on results of an early competition control study done in an attempt to establish a valuable oak component through enrichment planting of oaks in a productive first bottom site in a major river bottomland of South Carolina. Although site preparation was done after clearcutting, no attempt was made to establish a cultivated plantation of oaks in the classical sense. Results of earlier studies (Nix and Cox 1987, Nix and others 1985) indicated that planted oaks are persistent and successful provided they are not overtopped completely soon after planting. Thus, early competition control with no followup seemed feasible for establishing a viable oak component in these productive bottomland sites.

MATERIALS AND METHODS

A clearcut and windrowed first bottom, mixed hardwood stand on a fine silty clay loam soil (Chewacla series) along the Great Pee Dee River near Society Hill, SC was hand planted by the cooperating landowner, Sonoco Products Company of Hartsville, SC. One-year-old, bare root, cherrybark oak seedlings were obtained from a State nursery near Winona, MS and planted in February 1980. At a nominal spacing of 10 ft by 15 ft, the purpose initially was to establish about 300 oak seedlings per acre as an enrichment planting rather than a plantation, to ensure an adequate quality oak component on this productive site (SI_{50} = 95, for cherrybark oak). The study site was separated into three blocks according to drainage conditions and 4 groups of twenty seedlings were randomly selected in each block for an early competition control study.

Immediately following planting, seedlings of one group in each block were mulched with a 1.2 yd^2 sheet of heavy cardboard, manufactured by the cooperator. The cardboard sheets were slitted to the center to facilitate installation, with a small hole at the center for the seedling stem to pass through and were anchored with dirt clods. In May of that same year, a group of twenty seedlings in each block were shielded and 2 percent glyphosate herbicide was sprayed to full wetting in a 3-4 foot radius circle around each seedling. A third group of twenty seedlings were set aside as a control in each block. In the fall (October), seedlings in a fourth group in each block were sprayed with 2 percent glyphosate in the same manner as those in the spring. Each study seedling was marked with an aluminum tag, a 3 foot long white PVC stake, and mapped for future location. Study seedling sizes (basal diameter and height) were measured before and after the first growing season and after 6 growing seasons. Distance, height, and crown diameter of the nearest dominant woody competitor were also determined after 6 growing seasons. Analysis of variance and Duncan's New Multiple Range Test were used to ascertain significance of differences in treatment responses at the 5 percent level of probability.

RESULTS AND DISCUSSION

Since the one-year-old cherrybark oak seedlings used in the study were quite small, they were easily planted by contract tree planting crews using standard dibble bars and planting bags. The small root systems and stem size also greatly facilitated seedling lifting and handling. Pretreament measurements indicate no differences in the seedling size among treatments (table 1) although the small size of the seedlings was cause for concern as the site rapidly grew up in head-high weeds and sprouts.

Table 1.--Number, basal diameter, and total height of cherrybark oak seedlings at beginning of first growing season

Treatment	No. Trees	Basal Diameter (inches)	Total Height (feet)
Mulch	60	0.11a[1]	0.92a
Spring Herbicide	58	0.11a	0.88a
Control	59	0.11a	0.96a
Fall Herbicide	(Treatment applied October 1980)		

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

At the end of the first growing season, there were no differences in seedling size or survival among treatments, but some apparent difference in the actual amount of height growth was found (table 2). The seedlings of the spring herbicide treatment grew an average of 3.4 in in height, the cardboard mulch treatment seedlings grew 1.6 in, while the control seedlings grew only about 0.25 in due to top dieback of many seedlings.

The growth differential exhibited after the first growing season apparently was sustained for the next five years of the study period. After six growing seasons, the saplings released by early competition control were larger in diameter and height and had higher survival than did the control saplings (table 3). Although not statistically supported, the spring herbicide treatment appeared to provide the best early competition control of the treatments evaluated, as sapling average height of 8.6 ft seems better than the 7.9 ft average height of the other two treatments and is considerably better than the 6.2 ft average height of the control saplings.

Although planted oak survival after the first growing season was apparently unaffected by competition, survival after six growing seasons was considerably better where competition was controlled, i.e., 95 percent for the spring and fall herbicide treatments, 88 percent for the mulch treatment and 75 percent survival for the control planting.

Table 2.--Number, basal diameter, total height, growth, and survival of cherrybark oak seedlings after 1 growing season

Treatment	No. Trees	Basal Diameter (inches)	Height (feet)	Growth (inches)	Survival (percent)
Mulch	58	0.16a[1]	1.05a	1.56a	96.7a
Spring Herbicide	56	0.17a	1.16a	3.36b	96.6a
Control	55	0.13a	0.98a	0.24c	93.2a
Fall Herbicide	45	0.14a	1.04a	-----	-----

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

Table 3.--Number, basal diameter, total height, and survival of cherrybark oak seedlings after 6 growing seasons

Treatment	No. Trees	Basal Diameter (inches)	Total Height (feet)	Survival (percent)
Mulch	53	0.96a[1]	7.83a	88.3a
Spring Herbicide	55	1.07a	8.59a	94.8a
Control	44	0.59b	6.20b	74.6b
Fall Herbicide	43	0.85a	7.88a	95.6a[2]

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

[2] Value reflects survival 5 growing seasons after treatment.

The survival differential seems academic in view of the distance and size of the dominant woody competitors on the site (table 4). With an average height of over 13 ft and distance from planted oaks of less than 4 ft, these competing stems seem to be the dominant vegetation of the new stand. However, past experience has shown planted oaks to be persistent and, once reaching heights above 6 ft, to be very competitive as they begin rapid height growth, especially if they are not directly overtopped from above. The small but statistically significant differences in average distance to the nearest dominant hardwood competitor shown in table 4, e.g., 3.8 ft for the fall herbicide treatment versus 2.7 ft for the control, may translate into an important advantage in proportion of crown shaded when the height differential between planted oaks and nearest dominant competitor is triangulated relative to sun angle. In addition, small differences in available root space may be important in the competitive interaction at this age in the stand.

Table 4.--Average distance, total height, and crown diameter of nearest hardwood competitor after 6 growing seasons

Treatment	Average Distance (feet)	Total Height (feet)	Crown Diameter (feet)
Mulch	3.3ab[1]	13.5a	4.3a
Spring Herbicide	3.5a	13.7a	5.1a
Control	2.7b	13.5a	4.5a
Fall Herbicide	3.8a	12.7a	5.0a

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

The species composition of the dominant competitors may also make a difference in the success of the enrichment planting. Twenty-seven percent of the competitors were woody shrubs or midstory species such as sumac (Rhus copallina), hawthorne (Crataegus sp.), spice bush (Lindera benzoin), dogwood (Cornus florida), river birch (Betula nigra), alder (Alnus rugosa), and redbud (Cercis canadensis), not long term threats to 8 ft tall cherrybark oak saplings. However, 48 percent of the taller competitors were fast-growing pioneer species such as sweetgum (19 percent), loblolly pine (Pinus taeda - 16.5 percent), and elm, ash, sugarberry, cottonwood, sycamore, and red maple (Acer rubrum), 12.5 percent. Twenty-five percent of the dominant competitors were oaks, water (Q. niger) and willow (Q. phellos) oak (17 percent) and natural cherrybark oak (8 percent).

The planted oaks ranged from 1 ft to 17 ft in height and 0.1 to 3.4 in basal diameter, while the nearest dominant competitors ranged from 6 ft to 30 ft in height. These overlapping heights indicate that by chance or genetic variability some planted oaks may in fact be in a dominant or "free to grow" canopy position. An analysis of the field data comparing each planted oak height with the distance, height and species of its nearest dominant competitor revealed that there were differences among treatments in the proportion of planted oaks that were "free to grow," i.e., of equal or greater height than the competitor, of a distance from the competitor greater than or equal to its own height, or at least five feet tall with nearest competitor a less vigorous overstory, understory or midstory species. These comparisons revealed that 51 percent (150 stems/acre) of the fall herbicide treated oaks, 45 percent (135 stems/acre) of the spring herbicide treated oaks, 40 percent (120 stems/acre) of the mulch treated oaks and 34 percent (76 stems/acre) of the unreleased control oaks were, in fact, free to grow and potential crop trees. Assuming continued survival of these free to grow oak saplings and eventual attainment of the dominant canopy by at least half, which is quite likely, these numbers certainly provide a quality oak crop tree potential for the new stand. The data also indicate significant benefit of the early release treatments which nearly doubled the number of free to grow oak stems per acre through increasing survival and the apparent elimination of nearest dominant competitors.

A few pertinent observations can be made at this point. The natural cherrybark oak regeneration which was 8 percent of the total in the stand may provide nearly 300 quality "free to grow" stems per acre if numbers per acre can be derived from distance to nearest neighbor in randomly spaced populations as suggested by Smith (1983). Whether these natural oak saplings are sufficient stocking considering the presence of an average of nearly 3300 other dominant trees per acre is a question unanswered by this study. However, other stands visited in the area have little or no quality oaks at this stage. Are the planted oaks, even with 150 free to grow stems per acre, sufficient to provide a dominant quality oak component in fifty to sixty years when some of them will be beautiful sawtimber? The growth pattern of cherrybark oak in competition with the other woody species in this stand, excepting perhaps cottonwood and sycamore, both minor components, indicates that many of these saplings that are free to grow and greater than 6 ft in height will become members of the dominant canopy (Clatterbuck and others 1985, Clatterbuck and others 1987, Hodges and Janzen 1987).

And then, of course, there is the cost to be considered. The windrowing cost about $85 per acre, the herbicide treatments cost $41 per acre and the cardboard mulch treatment cost $97 per acre in 1980. Figured into a 50-year rotation these costs might be discouraging even with 100-200 quality oak crop trees per acre resulting. However, quality 2 and 3 log oaks may command as much as $300-$400 per thousand board feet stumpage in the quite near future. This increased stumpage value prospect along with 15-20,000 board feet per acre potential yields makes the economic outlook of these treatments much brighter. This economic outlook, however, is speculative at best and not a valid part of this study.

Perhaps more relevant is the observation that the mulch treatment was costly and difficult to apply and did not provide effective long term control of competing woody species. The fall herbicide treatment was also somewhat difficult to apply with locating and shielding the oak seedlings compounded by the head-high, rank vegetation of the near old-field conditions of the site, but was most effective in long-term control of competing woody species. The spring herbicide treatment was easiest to apply in the low, immature vegetation of the early growing season, provided reasonably good long-term control of competing vegetation, especially weeds and vines during the first year, and yielded the largest oak saplings of any treatment after 6 years, probably due to the advantage gained during the first growing season. The spring herbicide treatment also resulted in excellent 6-year survivals (95 percent) and satisfactory numbers of free to grow oak saplings per acre (135), especially if the natural cherrybark oak saplings are considered as part of the oak component.

Obviously, natural regeneration methods will remain the predominant choice of silviculturists for regenerating quality bottomland hardwoods in the South (Johnson and Shropshire 1983). This study has shown, however, that, when enrichment plantings are a desirable alternative, early competition control can be a valuable tool to insure successful establishment of an adequate number of free to grow quality oak saplings in the new stand. This finding could also have applicability to the problem of releasing natural oak seedlings from competing vegetation when advanced reproduction is not well-established prior to overstory removal and the rapid colonization of the site by pioneer species and residual sprouts. The longer term benefits accruing to seedlings released before completion of the first growing season observed in this study also argues for early competition control for small, young oak seedlings reproduced by any method, including direct seeding. Apparently benefits of early competition release are cumulative, at least for the six years encompassed by this study, as both size and competitive status of the spring herbicide treatment saplings are better than or equal to that of the more difficult to apply fall treatment.

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OBSERVATIONS ON RELEASE OF NATURAL PINE REGENERATION IN CUTOVER STANDS[1]

Michael D. Cain[2]

Abstract.--A study was installed in a poorly stocked, cutover loblolly-shortleaf pine (Pinus taeda L.-P. echinata Mill.) stand in southern Arkansas to determine if operationally prescribed release from woody and herbaceous competition would improve survival and growth of established, natural pine regeneration. For the four release treatments, pine growth trends in height and groundline diameter generally ranked as follows: annual release > hexazinone > glyphosate > check. The main benefit from the release treatments was to increase the percentage of stocked milacres with free-to-grow pine seedlings.

INTRODUCTION

Private nonindustrial forest landowners commonly harvest natural stands of loblolly and shortleaf pines (Pinus taeda L. and P. echinata Mill.) by cutting to a prescribed minimum diameter limit. Sawlog size pines, 10 inches d.b.h. and larger, are usually removed. The residual stands are often understocked with pines that had intermediate or suppressed crown classes in the former uncut stand and, therefore, have low potential for seed production. Under those circumstances, restocking from natural pine regeneration may be marginal, especially if the cut did not coincide with a good seed year.

Additionally, heavy cutting exposes the forest floor to full sunlight, promoting invasion and proliferation of early successional species. Vines, briars, woody shrubs, and hardwood trees can become rapidly established even after cutting of well-stocked pine stands. These herbaceous and woody plants can quickly overtop recently established pine seedlings and compete with them for growing space, sunlight, soil moisture, and nutrients. Under such conditions, the somewhat intolerant pine seedlings may linger in a suppressed state of growth for several years, and many eventually die. Further, these competitive influences can be particularly disruptive when stocking of the cutover site is limited to pine seedlings already established but having less than desirable levels of density and inadequate distribution over the area. This paper discusses the effects of treatments for releasing natural pine regeneration in poorly stocked, cutover pine stands.

METHODS

Study Area

This study was superimposed on three diameter-limit plots in a methods-of-cutting demonstration on the Crossett Experimental Forest, Ashley County, Arkansas. Soil on the study area is Providence silt loam (Typic Fragiudalf) and site index is 90 feet at 50 years for loblolly pine.

On the three diameter-limit plots, all pine sawtimber (trees larger than 11.5 inches d.b.h.) and all merchantable hardwoods were harvested in January 1943. In 1946 all hardwoods larger than 3.5 inches d.b.h. were cut to release pine reproduction. Subsequent harvests in 1953, 1958, 1968, and 1981, removed all pines larger than 11.5 inches d.b.h. Prescribed burning was done in March 1980. After the 1981 harvest, residual hardwoods greater than 1 inch at groundline diameter (g.l.d.) were injected with herbicide. In December 1982, density of pine seedlings (stems less than 0.6 inch d.b.h.) averaged only 240 stems per acre with 20 percent milacre stocking across the three diameter-limit plots. There were no pines in the 1-, 2-, or 3-inch d.b.h. classes. When the present study was installed in the summer of 1984, an abundance of herbaceous and woody species ranged up to 10 feet in height and covered all diameter-limit plots. In 1984, the few merchantable pines had an average basal area of only

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22 square feet per acre. All three diameter-limit plots were bordered by mature loblolly-shortleaf pines that provided an adequate seed source to restock the cutover areas.

Study Installation

Each of the three diameter-limit plots contained 4.4 acres and served as separate blocks for the present study. Diameter-limit areas were subdivided into four plots of 1.1 acres each with 0.5-acre interior measurement subplots. Four treatments were assigned completely at random within each of the three blocks. Response to treatments was assessed on 75 pine seedlings per interior 0.5-acre subplot. Seedlings were chosen on the basis of uniform spacing (17- by 17-foot grid) over each plot, and their competitive position ranged from overtopped to free-to-grow.

Treatments

Four treatments were randomly assigned within each block as follows:

Check--No treatment was imposed other than establishment of plot boundaries and tagging of 75 pine seedlings per plot (150 trees per acre).

Once-only application of broadcast spray herbicide--Glyphosate (Roundup®) was applied at the rate of 2 quarts per acre (2 lb a.i./ac) in 100 gallons of water per acre during September 1984. A tractor-mounted pump (Hypro® Roller Pump, model 7560C-T3) and hand-held sprayer (Spraying Systems Co. Gunjet® No. 43) were used to apply the herbicide at approximately 50 pounds-per-square-inch pressure. Spraying was done from a rubber-tire tractor (Ford® 532 diesel) in a checkerboard pattern by traversing each 1.1-acre plot in north/south and east/west directions on lines 36 feet apart.

Once-only application of soil-applied herbicide--Hexazinone (Velpar® L) was applied at the rate of 1.5 gallons per acre (3 lb a.i./ac) using a 1:1 water solution during April 1985. Spotgun herbicide applicators with adjustable dosage cylinders were used for treatment. Individual spots of 0.08 oz (2.5 ml) of solution were applied over each 1.1-acre plot on a 3- by 3-foot grid determined by ocular estimation.

Annual release by mechanical plus herbicide treatments--Inside a 4.5-foot radius from each pine seedling, all woody and herbaceous competition was reduced by cutting to a height below that of the 75 preselected seedlings during February 1985. To control regrowth of herbaceous plants, sulfometuron methyl (Oust®) was applied within the 4.5-foot radius at the rate of 5 ounces per acre (3.75 oz a.i./ac) in 55 gallons of water per acre during April 1985. Backpack sprayers (Solo® model 425) were used to apply the herbicide. The same technique was used to re-treat surviving pines in March 1986 and again in April 1987.

Measurements and Data Analysis

Before treatment, diameters at groundline were measured to the nearest 0.04 inch, and total heights were measured to the nearest 0.1 foot for all 75 preselected pine seedlings per plot. Such measurements of surviving seedlings were repeated i the fall of 1985, after 1 year's response, and in the fall of 1987, after 3 years.

After the 1987 growing season, density and milacre-stocking of pine regeneration were assessed on the 12 study plots. All submerchantable pines (trees less than 3.6 inches d.b.h.) were counted within 25 systematically established milacres on each treatment plot, but most of these pines were less than 1 inch in d.b.h. The dominant seedling o sapling on stocked milacres was categorized as being overtopped by competition or as free-to-grow.

Analysis of variance was used to evaluate treatment effects on pine survival, density, milacre-stocking, and free-to-grow condition. Analysis of covariance was used to evaluate pine growth responses to treatments. The covariates wer pretreatment groundline diameters and pretreatment heights. Percent values for survival, milacre-stocking, and free-to-grow condition were compared using the arcsine transformation. Duncan's New Multiple Range Test was used to isolate differences between treatment means. All analyses were carried out at the 0.05 level of significance.

RESULTS AND DISCUSSION

Pine Survival, Density, and Milacre-Stocking

The two operational herbicide treatments with glyphosate and hexazinone resulted in pine survival averaging 58 percent and 75 percent respectively after one growing season. This was significantly less than seedling survival on untreated checks (94 percent) or on the annual release treatment (97 percent). After 3 years, pine survival declined an additional 10 percentage points across all treatments. At that time, the glyphosate treatment had significantly lower survival for measurement pines than check plots or the annual release treatment, and pine survival on the hexazinone treatment fell between those extremes (table 1).

High seedling mortality was anticipated where glyphosate was oversprayed because of the presence of pine growth flushes that were associated with abnormally high rainfall in late summer of 1984, prior to treatment. When using glyphosate for pine release, the recommended procedure is to apply the herbicide after the pine winter buds have set (Monsanto 1985). Such timing, however, restricts application to a very narrow time frame. In a more recent investigation, Cain (1988) found that loblolly pine seedlings oversprayed with glyphosate in August had superior height growth the following year, with no reduction in survival, when compared to those oversprayed in September.

Table 1.--Condition of pine regeneration 3 years after application of release treatments

Treatment	Pine survival[1]	Regeneration inventory[2]		
		Density	Milacre-stocking	Free-to-grow[3]
	Percent	Stems/ac	Percent	Percent
Check	83ab[4]	2,067a	56a	21a
Glyphosate	51 c	3,240ab	69a	55 b
Hexazinone	65 bc	2,187a	61a	45ab
Annual release	88a	4,187 b	60a	63 b
Mean square error	37.6	7.89×10^5	15.8	87.9

[1] Based on 75 preselected pine seedlings per 0.5-acre plot.

[2] Based on 25 milacres per 0.5-acre plot.

[3] Percent of stocked milacres on which the dominant submerchantable pine was not overtopped by competing species.

[4] Columnar means followed by the same letter are not significantly different at the 0.05 level.

After the hexazinone treatment, less than 2 inches of rainfall was recorded during the next 30 days. Lack of precipitation may have reduced the efficacy of that herbicide for competition control while putting the pine seedlings in a stressed condition and thereby causing them to be susceptible to mortality from the soil-active herbicide.

If a release treatment is to be operationally effective in cutover pine stands that are already understocked, there must be a high rate of survival for the designated crop trees. Where an opportunity exists for additional natural seeding from residual cone-producing pines, then survival of established regeneration becomes less important. Therefore, the method used for release will depend on which situation the landowner encounters. Herbicide rates suitable for pine release may not be adequate for site preparation that enhances pine seedling establishment from natural seedfall.

Although both glyphosate and hexazinone tended to moderate the degree of competition during the first growing season after application, there was almost complete recovery by nonpine species within 3 years, based on subjective visual observation. Despite the pervasive competition, density of submerchantable pines averaged 2,920 stems per acre across all treatments in the fall of 1987, and milacre-stocking of those pines averaged 62 percent with unimportant differences between treatments (table 1). The increase in pine seedling density and percent stocking over that recorded in 1982 was the result of a bumper seed crop in the winter of 1983-84 (Cain 1987). Natural regeneration of loblolly and shortleaf pines is considered to be successful on cutover areas if density averages 700 seedlings per acre within 3 years after harvest (Grano 1967) and milacre stocking is at least 60 percent (Trousdell 1963). Although nonpine vegetation exhibited a rank appearance, about 54 percent of stocked milacres had pine regeneration that was free-to-grow on treated plots; but nearly 80 percent of dominant pine regeneration within stocked milacres on check plots was judged as overtopped by competing species (table 1).

Pine release by glyphosate, hexazinone, or annual release treatments did not improve survival of established pine seedlings nor density and distribution of all pine seedlings when compared to untreated checks and when applied as described in this study. On the positive side, the release treatments did tend to increase the percentage of pine regeneration that was free-to-grow. Three years after release, significantly more pine seedlings were free-to-grow on plots treated with glyphosate and annual release as compared to checks (table 1).

Pine Seedling Growth

After one growing season, no statistically significant differences were shown in pine growth responses to release treatments (table 2). During three growing seasons, however, pine regeneration on plots treated with hexazinone or annual release averaged significantly better growth in height and g.l.d. than untreated checks. Pine seedlings released by hexazinone and annual release grew about 1.6 feet taller and about 0.5 inch larger in g.l.d. than untreated checks after 3 years (table 2). No significant gains in pine growth were evident from glyphosate applications. In the fall of 1987, 6 years after the diameter-limit cut, surviving measurement seedlings in this study averaged 5.3 feet in height and 1.01 inch in g.l.d. across all four treatments.

Table 2.--Mean per-tree growth of surviving measurement seedlings following release treatments

Treatment	First year's growth		Three year's growth	
	Height	G.L.D.	Height	G.L.D.
	Feet	Inches	Feet	Inches
Check	0.75a[1]	0.12a	2.92a	0.49a
Glyphosate	0.53a	0.19a	3.08ab	0.64ab
Hexazinone	0.82a	0.16a	4.38 bc	0.93 bc
Annual release	0.81a	0.18a	4.65 c	1.11 c
Mean square error	0.03	0.002	0.40	0.03

[1] Columnar means followed by the same letter are not significantly different at the 0.05 level.

Treatment Cost

Cost figures were computed from average worker-hours with a minimum wage of $3.35 per hour. Tractor time was based on USDA Forest Service operating and replacement costs for fleet equipment. Herbicide volumes were based on 1983 retail prices from chemical supply outlets. Treatment costs were as follows:

Treatment	Cost per acre
Glyphosate (1 yr)	$55
Hexazinone (1 yr)	$79
Annual release (3 yr)	$172

Cost of the annual release treatment was about $57 per acre per year, which is comparable to the two operational treatments if applied only once. These costs do not include purchase prices of backpack sprayers, tractor-mounted sprayers, or handtools.

CONCLUSIONS

A more cost effective release treatment is needed than the three tested in this study if release of natural pine regeneration is to be accomplished on an operational basis. Lack of significant pine growth response from glyphosate treatment and high mortality of established pine seedlings on the two operational treatments (glyphosate and hexazinone) suggest that more thought should be given to competition control efforts before harvest rather than several years after establishment of pine seedlings. That is especially true on cutover areas where there is no pine seed source that could replace established seedlings that might be killed by release treatments. Probably the most important finding in this study was that, during a 3-year period, pines on check plots performed almost as well as treated pines in growth and had excellent survival with no additional cost to the landowner. Data from this investigation confirm that pine seedlings exhibit a positive growth response to release from competing vegetation, but additional research is warranted to determine if there is a need for release during the years preceeding merchantability.

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CHANGES IN VEGETATION UNDER FOUR BURNING REGIMES[1/]

Earle P. Jones, Jr.[2/]

Abstract.--During 7 years before seed-tree harvest, plots in a mature Georgia Piedmont loblolly pine stand received one of four treatments: annual winter fire, 3-year periodic winter fire, 3-year periodic summer fire, and unburned check. Vertical projection of the 8-foot tall understory, which was measured annually in the fall, initially showed that 60 percent of the understory was of species that compete with pine regeneration. Average 7-year effects were that all burns reduced hardwoods 15 percentage points, while hardwoods increased 12 percent on check plots. Herbaceous cover increased 18-24 percent on winter-burned plots and 3 percent on summer-burned plots. Vines were not significantly reduced by burning. Burning at 3-year intervals was more effective than annual burning, and periodic summer fires gave best results.

INTRODUCTION

Natural regeneration of loblolly pine (Pinus taeda L.) may fail or be delayed because of too much understory competition during the seedling establishment period of the new rotation. A single preparatory fire at harvest or regeneration time does little to control hardwood competition larger than 3 inches d.b.h. Better control can be achieved with a series of prescribed fires late in the previous rotation to restrict development of small stems and shrubs before they become too large. Chemical and mechanical control of hardwoods at regeneration time are effective but more costly than burning.

Many owners of small forest properties would elect to use prescribed fire and natural regeneration to avoid the high cost of site preparation and planting, but they need convincing evidence that competing hardwoods can be controlled and that loblolly pine will be established. Questions also arise about how often and in what season prescribed burning should be done.

The study described here was undertaken to quantify the amount of hardwood control in a mature loblolly pine stand, and to compare the relative change in understory vegetation, caused by three burning regimes and an unburned check. The treatment period was the last 7 years before harvest. The study was installed on a Piedmont site on the Hitchiti Experimental Forest in central Georgia. A follow-up study will evaluate pine stocking and competition after a seed-tree cut.

METHODS

Preburn Conditions

In 1978 when the study was installed, the study area supported a mature stand of loblolly pine averaging 76 years old. Trees in the age sample, taken from the dominant portion of the stand, ranged from 64 to 102 years old. Dominant tree heights ranged from 74 to 112 feet, and 50-year site index was 80. The study was installed on two northeast slopes of 15 and 20 percent. The merchantable-size portion of the stand averaged 153 pine trees per acre and 115 square feet of basal area, plus 32 merchantable-size hardwoods having 8 square feet of basal area. Mean merchantable stand diameter was 11.7 inches for pines, and 7 inches for hardwoods.

Hardwood stems less than 4.6 inches d.b.h. were counted on milacre plots in November

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[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Table 1.--Changes in percent of 8-foot tall shade cover on transects from preburn (1978) to the average postburn cover (1979-85) among treatments, by vegetation categories.[1]

Vegetation categories	Preburn (1978)	Treatments			
		Annual winter	Periodic winter	Periodic summer	No burn check
	Percent				
Unoccupied	36.6	-2.0b	0.6b	19.4a	-5.8c
Pine	3.1	-3.4c	-0.8b	-2.4c	1.3a
Herbs	11.9	23.9a	17.3b	3.0c	-4.7d
Vines	17.7	-6.1b	-1.6a	-2.7ab	-4.8ab
Shrubs	5.4	2.7a	-1.3b	-1.4b	2.4a
Hawthorn	3.1	-3.6b	-3.7b	-0.4a	-1.0a
Dogwood	14.6	-9.2bc	-6.5b	-10.6c	8.1a
Oaks	1.5	-1.0b	-1.6b	-0.7b	0.7a
Gums	2.8	-0.1b	-0.8b	-0.2b	0.8a
Other hw's	3.6	-1.0b	-1.6b	-4.0c	2.8a
All hardwoods (incl hawth)	25.5	-15.1b	-14.1b	-15.3b	11.5a
All veg. other than pine	60.4	5.5a	0.2b	-17.0c	4.5a

[1] On each line, means followed by the same letter do not differ significantly at the 0.05 level, according to Duncan's multiple range test.

1978. There were 4892 small hardwood stems per acre, including hawthorn (Crataegus spp.). Dogwood (Cornus florida L.) contributed 42 percent of this number, oaks (Quercus spp.) 14 percent, and sweetgum (Liquidambar styraciflura L.) and blackgum (Nyssa sylvatica Marsh.) only 4 percent.

Forest managers in the Georgia Piedmont often consider sweetgum the chief hardwood problem species, but in this study area dogwood was the most frequently occurring hardwood species in the understory. Other understory hardwoods included maple (Acer spp.), hickory (Carya spp.), persimmon (Diospyros virginiana L.), black cherry (Prunus serotina Ehrh.), elm (Ulmus spp.), and ash (Fraxinus spp.).

Before burning treatments were started, vertical ground shade from vegetation up to 8 feet tall was estimated on line transects (table 1). About 60 percent of the ground was shaded by vegetation other than pine. Vines shaded 18 percent of the ground, and dogwood 15 percent. All hardwood vegetation, including hawthorn, totaled 26 percent.

The study area had not been burned in 16 years, and fuel loading averaged 9.4 tons per acre when the first fires were set.

TREATMENTS

The study was laid out in four randomized complete blocks, with 2 blocks located on each of the two slopes. Treatment plots averaged 0.35 acre each. The long dimension extended the full length of the slope, from the ridge almost to the stream bank, a distance that varied from 2.3 to 4.8 chains among plots. All burning treatments started in 1979. The four treatments were: (1) annual winter fire, (2) periodic winter fire, (3) periodic summer fire, and (4) no fire. Periodic burning was done at 3-year intervals.

Fire Prescription

The plan specified that winter burns be in January and summer burns in June or July (table 2). Burning was prescribed according to guidelines given for southern forests (Mobley et al. 1978). As often is the case, it was not always possible to burn exactly within the prescribed conditions. Winter burns were in January only once, the rest were in February and March, the latest being March 10. Ambient temperatures during winter fires were usually a little higher than prescribed, usually about 60 to 70 °F, which was necessary to get good drying. Wind direction was seldom steady out of the north, and tended to be too low for good burning. Fuel moisture was a little higher than 20 percent on 3 of the 9 burns.

Table 2.--Prescribed and actual conditions for burning treatments

		Air	Rel.	Wind		Fuel
Season	Date	temp.	hum.	Dir.	Speed	moist
		°F	Pct.		Mph	Pct.
Prescribed						
Winter	Jan	20-50	20-60	N	1-5	10-20
Summer	Jun-Jul	80-95	20-60	N	1-5	10-20
Actual						
Winter	2-13-79	50-60	22-36	S	2-3	--
"	2-27-80	46-60	28-37	SW	5-10	16-22
"	2- 5-81	37	30	E-W	0-2	25
"	3-10-82	70	38	S	0-6	13
"	3- 9-83	61	40	NW	3-8	27
"	2-10-84	66	53	S	0-6	20
"	1-14-85	48	32	NW	2-3	24
Summer	6-12-79	80-86	31-35	NE	3-5	15
"	8-26-82	85	50	S	0-4	17
"	7-11-85	95	38	SW	2-5	13

The burning technique used generally simulated a strip headfire, but because of plot size and shape (0.35 acre and rectangular), it often tended to be a ring burn. Burning time on all plots averaged 37 minutes.

Data Collection

Vegetation was measured on a series of nine vertical line transects on each treatment plot. Lines were on contour in groups of three at upper, mid, and lower slope positions. Each transect was 33 feet long and had a permanent iron pin at each end, A and B. When data were collected a measuring tape was stretched from A to B and secured in place with a small clamp. The zero end of the tape was always indexed at A.

Remeasurements were made annually from 1979-85, in the fall, usually October, except for two years when they were made early in November. Efficiency of remeasurement was improved by making observations when vegetation colors just began to change, which helped distinguish the various species. This time varies with the season, but in middle Georgia is usually best in the first or second week of October. Grape leaves usually begin to fall first, and a late measurement may cause vines to be underestimated.

Understory vegetation was recorded in 10 categories or species groups: unoccupied by live vegetation, pines, herbaceous, vines, shrubs, hawthorn, dogwood, oaks, gums, and other hardwoods. Later in the analysis three summary groups were added.

The 33-foot line transect was divided into 66 linear units. Each 6-inch line segment was observed for the predominant vegetation in the vertical plane from groundline to a height of 8 feet. Each 6-inch segment was assigned to only one vegetation category, and there was no provision for overlapping vegetation. If no one category was predominant, the type closest to the ground was chosen. The observer carried an 8-foot range pole to help in plumbing the the vertical plane at each 6-inch segment, and to determine the 8-foot vertical limit.

Data were recorded on a tally sheet designed as a facsimile of the 33-foot linear transect, numbered in feet and marked in 6-inch units. On this sheet, observations were recorded as one-letter symbols representing the various categories. One code letter could represent a single 6-inch segment, or a long string of segments joined on the tally by pencil line. These same letter symbols, along with identifying information about measurement date, block, treatment, and slope position, were transferred to computer files as data lines representing the 66 transect line segments.

Milacre plot data were also taken, but only the vertical line transect data are reported here.

Analysis

Observations in each vegetation category were totaled for the three transect lines at each slope position on a treatment plot, and for the nine lines per treatment plot. These summarized observations were then converted to percent coverage for each vegetation category at each slope position and for each treatment plot.

Percent coverage for each vegetation category was plotted over years, by treatments. It was obvious that response data were heavily influenced by the year of measurement in relation to the year of treatment, especially for the periodic treatments. For example (fig. 1), periodic burning caused sharp drops in all hardwoods, taken as a group, in 1979, 82, and 85, the years that those treatments were applied. To use comparisons based on a single year's results, or the accumulated effects of treatments at the end of the study, would bias the results toward the treatment with the most recent burn. Therefore, an average annual response in each vegetation category was used in further analysis.

The change in coverage from 1978 preburn conditions to each postburn year was calculated as: (current year percent coverage) minus (1978 percent coverage). These calculations were made for each slope position and treatment plot. Negative values indicated a decrease in percent coverage from 1978 to the current year. These change values were then averaged across years to calculate the average change in each vegetation category caused by each burning regime.

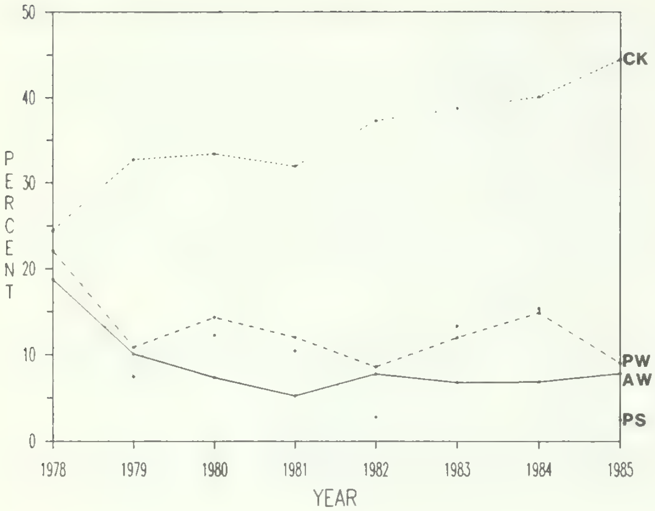

Figure 1.--Average annual transect shade cover for all hardwoods, by treatments: annual winter (AW), periodic winter (PW), periodic summer (PS), and unburned check (CK). Periodic fires were at 3-year intervals.

Separate analyses of variance were performed on these data for each of the 10 vegetation categories. Percent coverage values were not transformed to the arcsin square root of percent because of the negative percent values. Mean changes in percent cover for each vegetation category were then compared among treatments by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Analysis of variance of the mean annual change in percent coverage for each of the 10 vegetation categories showed that year effect continued to be significant in 5 out of the 10 vegetation categories, despite averaging over the seven response years. This effect can be attributed to the yearly differences in burning conditions such as fuel and weather. Although there was no good measure of it, fire intensity varied considerably among years.

Slope position was significant in 3 out of the 10 vegetation categories. Although this result suggests separate analyses for each slope, it is impractical to assume fire prescriptions would be made for anything but the total run of the slope.

Effects of treatments on the mean annual change in percent coverage was significantly different among treatments for all vegetation classes (table 1).

The unoccupied category, having no live vegetation up to 8 feet, is a desirable goal for natural regeneration. Periodic summer burns increased open space 19 percentage points, significantly more than all other burn treatments (table 1). Unburned checks reduced open area by 6 percentage points. Annual and periodic winter burns gained very little or none in the unoccupied category, mainly because this space was taken up by herbaceous vegetation during the growing season from winter burning until fall measurement.

Pine stocking in this study is not an important consideration since the purpose of burning is to prepare the site for a future pine seedling crop.

Herbaceous cover increased 24 percentage points in the annual winter treatment, significantly more than in any other treatment (table 1). Summer fire produced only a modest gain in this category because of the short growth period remaining in the season after burning.

Fire did not consistently reduce the area occupied by vines in this study. Vine control was best on annual winter burns, but was not significantly better than for the unburned check.

Shrub coverage was reduced slightly in both the periodic winter and periodic summer treatments, and it increased by 2-3 percent on annual winter and check plots.

Hawthorn declined on all treatments, including the unburned check. By the end of the seven-year response period, hawthorn coverage was zero on all burn treatments compared to less than 3 percent on the unburned treatment. Brender and Cooper (1968) noted that hawthorn is a relatively weak sprouter, compared to dogwood and sweetgum.

Dogwood had the most potential as a competitor against pine seedling establishment. Fire reduced dogwood by 6 to 11 percent, with periodic summer burning having the most effect (table 1). Dogwood increased by 8 percent on the unburned check.

All burning treatments reduced the coverage of oaks, gums, and other hardwoods. There was no significant difference among burning treatments on the reduction in these three categories, except that periodic summer fire had the greatest effect on the "other hardwood" group.

In order to focus on the overall effect of treatments on species most likely to compete with pine seedlings, vegetation categories were combined and analyzed (table 1). First, all hardwoods, including hawthorn, were combined. The burning treatments reduced this category by about 15 percentage points, compared to a 11 percent increase on the untreated check.

Secondly, all vegetation except pine and unoccupied space were combined. Periodic summer burning reduced this combined coverage by 17 percent,significantly more than any other treatment. Annual winter fires and no burning led to an increase in total nonpine coverage.

For the annual winter burn treatment, this increase was largely herbaceous cover.

Burning treatments reduced all woody species that may compete with pine seedlings, while all these species, except hawthorn, increased on the unburned plots. On the other hand, herbaceous cover increased on burned plots and decreased slightly on unburned plots. Sparse herbaceous cover may not be a serious threat to pine seed germination because it dies back in the winter, and it provides some protection to succulent germinates in the first spring and summer. Herbaceous cover has the best opportunity to develop between a winter burn and the following pine seedfall in October-November. Summer burns significantly reduce the herbaceous invasion because of the shortened regrowth period before fall die-back.

In summary, all burning treatments reduced hardwood coverage by an average of 15 percentage points over the 7-year response period. Annual and periodic winter burns increased herbaceous cover by 24 and 17 percent, respectively. Vines were not significantly reduced by burning treatments, compared to unburned checks. Burning treatments reduced percent coverage of dogwood by 7 to 11 percentage points, while dogwood coverage increased by 8 percentage points on check plots. Periodic summer burning was most effective in reducing vegetative cover near the ground, and was significantly better than other burning treatments in creating unoccupied space.

Annual winter burns were more difficult to apply because sufficient fuel does not accumulate from one year to the next to carry a fire. Three-year periodic fires burn in a much more continuous pattern. Average burning times on the periodic burn treatments in this study were only 63 percent as long as for the annual burns. Quicker burning and less frequent applications favor periodic burning for cost savings. There was no appreciable difference in burning times for periodic winter and summer burns.

CONCLUSIONS

Based on these results, loblolly pine stands being managed for natural regeneration in the Georgia Piedmont benefit significantly by burning to control vegetation up to 8 feet tall. Burning at 3-year intervals is preferable to annual burning, and summer burning is better than winter burning in controlling hardwood competition.

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THE EFFECTS OF VARYING DEGREES OF CROWN SCORCHING ON GROWTH AND MORTALITY OF A YOUNG PIEDMONT LOBLOLLY PINE PLANTATION[1]

D. Thompson Tew, Larry G. Jervis, Donald H. J. Steensen[2]

Abstract.--A 14-year-old loblolly pine plantation was prescribe burned in November 1981, resulting in crown scorch on many of the crop trees. This paper documents growth and mortality responses as a function of percent crown scorch through four growing seasons following the burn. Diameter growth was most severely affected in the first year following prescribe burning, with decreasing diameter growth as percent crown scorch increased. At the end of 4 years, trees with crowns scorched 61-80 and 81-100 percent had grown an average of 35 and 60 percent, respectively, less in diameter than did trees outside of the burned area. Height growth was most affected in the second and third seasons. Estimates of volume growth over the 4-year period indicate a loss of approximately 450 cubic feet per acre in this stand as a result of crown scorching.

INTRODUCTION

Prescribed burning in southern yellow pine stands is a long accepted silvicultural tool used for the reduction of hazardous fuel levels and control of hardwood competition. Crown scorching (browning of needles), crown consumption (blackening of needles) and stem bark char often result from prescribed burning, particularly when fire is used during marginal or poor weather conditions. Crown scorching is a commonly accepted diagnostic criterion used to indicate fire induced injury (Hare 1961). The objectives of this study were to quantify the effects of crown scorching on growth, mortality and stand development of a 14-year-old loblolly pine plantation following a winter prescribed burn.

The effect that crown scorching has on growth and mortality has been the subject of numerous studies; however, the results of these studies are highly variable and often contradictory. Villarrubia and Chambers (1978) found that scorching 0 to 33% of the crown resulted in an increase in diameter growth following an October burn in a 20-year-old loblolly pine plantation, but that diameter growth decreased as percent crown scorch increased above 66%. Neutral or positive growth responses following low levels of crown scorching have been documented in other studies (Johansen 1975; Lilieholm and Hu 1987). However, Johansen and Wade (1987) found that even slight scorching (0-10%) resulted in a 15% decrease in mean 2-year radial growth following a winter burn in a 25-year-old slash pine plantation. Three important factors thought to be responsible for affecting survival and growth following prescribed burning are timing of defoliation, level of defoliation and species differences in bud development (Wade and Johansen, 1986). In addition, weather patterns, particularly annual rainfall before and after burning, may have a significant effect on the magnitude of fire induced responses (Zahner and Saucier 1988).

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MATERIALS AND METHODS

The study area is a Piedmont loblolly pine plantation established in January 1968 at North Carolina State University's Hill Forest. This forest is used for research, demonstration and operational forestry, and is located in Durham Co., NC within the Carolina Slate Belt (N.C. Agricultural Research Service 1984). Soils on the site are of the Georgeville series (Clayey, kaolinitic, thermic Typic Hapludults) with a site index (base 50) of 80 feet. Average rainfall for the area is 44.8 inches per year[3/]. This area has a long history of agricultural use and evidence of past farming practices were present within the stand. The plantation is on an east facing slope (2 to 10%), and at age 14 had a density of 608 trees per acre with an average diameter of 5.0 inches. The understory was perdominantly hardwood seedlings and saplings with areas of dense honeysuckle.

On November 12th and 13th, 1981, a portion of the plantation was prescribe burned using strip and spot-strip head fires for understory fuel reduction. High ambient temperatures averaged 54° F, with mean relative humidity of 32% and winds out ot the north-west at 17-24 mph. Evidence of crown scorching soon appeared. Total rainfall for the years 1980 and 1981 was 35.6 and 36.4 inches, respectively. Therefore, this stand may have been under some degree of drought stress at the time of burning. To assess the effect crown scorching might have on diameter and height growth, 120 trees within the burned area were selected, tagged (at breast height) and measured in January and February, 1982. Twenty trees were selected in each of six crown scorch classses (0-3%, 4-20%, 21-40%, 41-60%, 61-80% and 81-100%) based on a subjective estimation of the length of scorched crown relative to total crown length. Twenty trees in the adjacent, unburned portion of the plantation were also tagged and measured as controls. In an effort to minimize variation in growth due to factors other than crown scorching, the following guidelines were adhered to during sample tree selection:

1. Trees were chosen in close proximity (within 60 ft) to a transect line established along the contour through the center of the stand.
2. Sample trees were of dominant or codominant crown class.
3. No more than three trees in one crown scorch class were chosen consecutively.
4. No trees exhibiting abnormal growth or form were selected.
5. Sample trees were at least one row away from roads or firelines.
6. No trees with crown consumption were chosen.

Diameters were measured (outside bark) to the nearest 1/100th inch using a diameter tape, and heights measured to the nearest 1/10th foot with an extendable fiberglass pole. Sample trees were remeasured in the same manner during the four subsequent dormant seasons, and annual diameter and height growth determined. Initially, the range in sample tree mean diameters between scorch classes including the

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[3/] U.S. Dept. of Commerce, N.O.A.A., National Weather Service - Observation Dept., Raleigh-Durham Airport.

control was 6.36 to 6.59 inches with an overall mean of 6.47. Average heights ranged from 39.8 to 41.5 feet. An analysis of variance on original diameters and heights indicated no significant differences between scorch classes or the control (tables 1 and 2).

In addition to the sample trees, eight 1/20th acre permanant plots were established within the burned area to determine mortality and facilitate estimations of stand development. Diameter breast height, crown class and crown scorch class were recorded for trees within these plots. These trees were remeasured the first and second year following the burn.

RESULTS

Both diameter and height growth were significantly affected by crown scorching for three growing seasons following the burn (tables 1 and 2). In order to detect significant differences between individual scorch classes, paired T-tests were performed at an alpha level for individual comparisons of 0.0174. This analysis yields an experiment-wide confidence rating of 90% (Steele and Torrie 1980).

Diameter growth in the first year following the prescribed burn was most dramatically affected by crown scorching. Without exception, an increase in the degree of crown scorch severity resulted in a

Table 1. — —Initial diameter, annual diameter growth and final diameter by percent crown scorch class.

Percent Crown Scorch	Initial Diameter (inches)	First Year's Growth	Second Year's Growth	Third Year's Growth	Fourth Year's Growth	Final Diameter
Control	6.55(a)	0.45(a)	0.30(a)	0.35(a)	0.20(a)	7.85(a)
0-3%	6.36(a)	0.36(b)	0.25(ab)	0.29(abc)	0.18(a)	7.44(ab)
4-20%	6.41(a)	0.33(bc)	0.26(ab)	0.30(ab)	0.20(a)	7.50(ab)
21-40%	6.54(a)	0.26(cd)	0.22(b)	0.28(abc)	0.20(a)	7.51(ab)
41-60%	6.59(a)	0.23(d)	0.25(ab)	0.29(abc)	0.23(a)	7.60(ab)
61-80%	6.46(a)	0.15(e)	0.22(b)	0.26(bc)	0.20(a)	7.30(ab)
81-100%	6.41(a)	0.02(f)	0.12(c)	0.21(c)	0.16(a)	6.94(b)

Table 2. — — Initial height, annual height growth and final height by percent crown scorch class.

Percent Crown Scorch	Initial Height (feet)	First Year's Growth	Second Year's Growth	Third Year's Growth	Fourth Year's Growth	Final Height
Control	41.5(a)	3.2(a)	2.8(a)	2.8(a)	2.3(a)	52.6(a)
0-3%	41.0(a)	2.8(ab)	2.2(ab)	2.5(ab)	1.7(a)	50.1(ab)
4-20%	40.6(a)	2.7(ab)	2.1(ab)	2.2(ab)	2.3(a)	50.0(ab)
21-40%	39.9(a)	3.0(a)	2.0(b)	2.0(ab)	1.4(a)	48.3(b)
41-60%	39.8(a)	3.1(a)	1.8(b)	1.9(ab)	1.4(a)	48.1(b)
61-80%	40.2(a)	2.8(ab)	1.6(b)	1.8(b)	1.8(a)	48.2(b)
81-100%	40.6(a)	1.8(b)	1.5(b)	1.6(b)	1.7(a)	47.2(b)

Observations with same letter are not significantly different (α=0.0174) decrease in diameter growth during this period, with the highest scorch class essentially putting on no diameter growth. The fact that the lowest scorch class (0-3%) also grew significantly less than did the control is an · indication that the burn might have had an effect on other stand characteristics such as soil chemical or physical properties, small root turnover, or cambial damage; however, our data are too limited to substantiate this possibility. The trend of lower growth with increasing scorch, although less severe or uniform, was also evident in the second and third growing seasons. In the fourth year following the burn there was no significant diameter growth differences attributable to crown scorching. During this four year period, trees in the 61-80 and 81-100% scorch classes grew and average of 35 and 60% less, respectively, in diameter than did the control trees.

Although unexpected, there were significant differences in height growth in the first year following burning. A 1.4 foot difference in average height growth between the control trees and the 81-100% scorch class trees can be attributed for the most part to loss of the terminal leader in several of the scorched trees, forcing a lateral branch to assume dominance. The exact reason for this condition is not known at this time, however it was not observed on trees in other scorch classes.

Response of height growth to crown scorching was more evident in the second and third years after the burn. During both of these seasons, height growth decreased with increasing percent scorch. This relationship would indicate decreased stored energy reserves in the dormant seasons following the burn due to lower leaf area and increased energy expenditures to replace needles (Kramer and Kozlowski 1979; Zimmermann and Brown 1977). As with diameter growth, no differences in height growth were evident in year four.

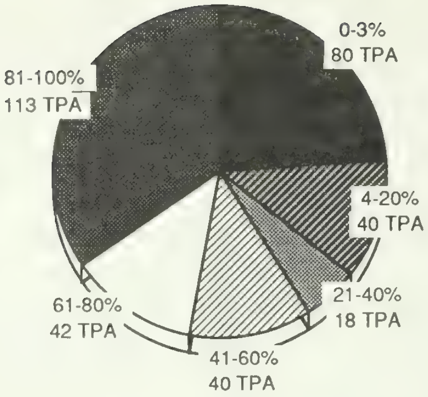

Figure 1. Initial trees per acre by percent crown scorch classes.

The impact of crown scorching on a stand basis is a function of growth responses to scorching, the number of trees affected and scorch related mortality. Figure 1 shows the number of dominant and codominant trees per acre by scorch class within the burned area. Although precautions were taken to minimize the intensity of the fire, a heavy fuel load and marginal burning conditions resulted in 34% of the trees being scorched greater than 80%. Heavy scorching also had an effect on survival (fig. 2). In the first year following the burn, 4% (13 trees per acre) of the upper canopy trees died, all of which were in the 81-100% scorch class. Spatially, most of the trees that died were clumped together, resulting in small openings in the stand.

To quantify the effect of crown scorching on volume growth per acre, the orginal stand table was projected assuming the stand was

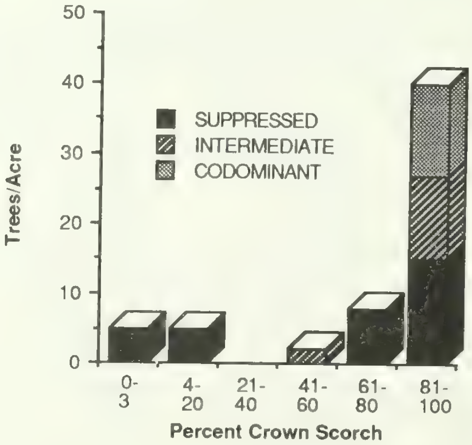

Figure 2. Mortality by crown class within percent crown scorch classes.

1) not burned and 2) burned. Four year diameter projections were calculated for dominant and codominant trees using methods described by Davis (1966). Based on data from the sample trees, stand table projections were made using first the diameter increments of the control trees, and second the diameter increments of the different scorch class trees as they applied to the actual frequencies of scorch classes within the stand. Final volumes were calculated for the sample trees based on formulas developed by Amateis and Burkhart (1987), and regressions of final volume on final squared diameter were developed in order to produce local volume tables for each scorch class. (R-squares ranged from 0.94-0.98). These volumes were then applied to the projected stand tables to determine volume per acre with and without the burn. Only dominant and codominant trees were considered in this analysis because all sample trees were of the dominant or codominant class.

Initially this stand supported a volume of 1218 cu ft/acre and 333 dominant or codominant trees/acre. Figures 3 and 4 graphically depict projected stand and stock tables with and without the burn. Due to the relatively large number of trees in the higher scorch classes, burning this stand had the effect of shifting the mean and modal diameters to lesser values. Since volume is a function of diameter squared and height, final volume was more affected by scorching than diameter or height. Projected volume without crown scorching is 2286 cu ft/acre, with a mean annual increment for the period of 267 cu ft/acre/year. Projections made based on diameter growth of the scorched trees yields a final volume of 1837 cu ft/acre and 155 cu ft/acre/year for the four growing seasons. Estimated 4-year loss in volume attributable to crown scorching is 449 cu ft/acre. Whether or not this loss will be carried throughout the rotation, or whether the stand will recover due to lower competition, is unknown at this time.

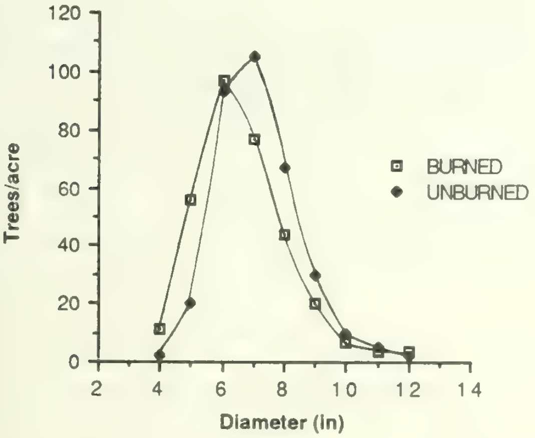

Figure 3. Stand table projections with and without crown scorching.

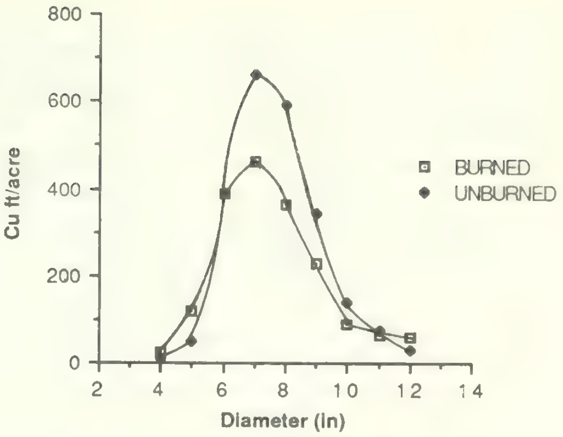

Figure 4. Stock table projections with and without crown scorching.

CONCLUSIONS

Prescribed burning of loblolly pine plantations is an economical means of reducing fuel levels and understory competition. Some crown scorching is not unusual following a prescribed burn; but, the intensity and extent of scorching as encountered in this study can have substantial negative effects on tree and stand development. In this case, increases in percent crown scorch resulted in significant decreases in first year diameter growth of dominant and codominant trees. Trees scorched greater than 60% also showed decreased diameter growth in the second and third growing seasons following prescribed burning of this 14-year-old plantation. Height growth was most notably affected in the second and third growing seasons following burning, with decreasing height growth corresponding to increasing percent crown scorch.

Crown scorching also had an effect on mortality. Twelve percent of the upper conopy trees scorched greater than 80% died in the first year following burning. No dominant or codominant trees in lower scorch classes suffered mortality during this period. Projections of volume per acre four years after prescribed burning of this stand indicate a loss in growth of 449 cu ft/acre due to crown scorching. If this volume loss is not recovered in subsequent years, the outcome will be either lower volume at harvest or a longer rotation.

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Growth and Yield

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A STAND TABLE PROJECTION APPROACH TO YIELD PREDICTION IN UNTHINNED, EVEN-AGED STANDS[1]

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Abstract.--A stand table projection system based on relative tree basal area is presented. Relative tree basal area is defined as the ratio of individual tree basal area to mean basal area in the stand. Given acceptable survival and per-acre basal area projection equations, an initial tree diameter list or stand table is projected to some future age. The system is designed to predict a future stand table consistent with predicted survival and per-acre basal area. Remeasurement data from slash pine (Pinus elliottii Engelm.) growth and yield sample plots located in the coastal plain of Georgia, Florida and South Carolina were used to validate the system over a range of site indices and densities. The data are used to develop survival and basal area projection equations and to demonstrate the stand table projection system.

INTRODUCTION

Estimates of current yield in southern pine plantations are generally obtained in one of two ways. Stand-level values such as age, trees per acre, basal area per acre, and some measure of site quality can be used as inputs in an appropriate yield prediction equation. If a tree list or per-acre stand table is available, an individual-tree volume equation can be used and per-acre yield estimates are obtained by summing individual tree or diameter class volumes. To estimate future yield, projected stand variables must be calculated and used in the yield prediction equations, or a future tree list or stand table must be constructed.

Traditional stand table projection systems estimate future tree sizes based on measurement of past growth rates in a stand. Adjustments for mortality and ingrowth are made in the projected stand table before volume calculations are made (Meyer 1935; Chapman and Meyer 1949; Avery 1975; Clutter et al. 1983). This approach is inherently inaccurate in even-aged stands. Growth rates may change with time due to increasing basal area of trees, increasing intra-species competition, or attainment of physical maturity in a stand (Chapman and Meyer 1949). The system is heavily dependent on reliable estimates of ingrowth and mortality. Such estimates can be effectively obtained only through remeasurement data from representative stands (Avery 1975).

In this study, an attempt was made to develop a stand table projection system consistent with reliable predictions of survival and per-acre basal area. Diameter growth estimates were based on a tree's size relative to its competitors. Remeasurement data were used to examine the development of trees of different relative sizes under varying stand conditions. The procedure is based on an earlier study by Clutter and Jones (1980).

METHODS

Growth and Yield Sample Plots

Data for this study came from growth and yield sample plots located in slash pine plantations in South Carolina, Georgia, and north Florida. Plantations were at least 10 years old, were planted after mechanical site preparation, were unthinned and unfertilized, and had no evidence of excessive insect or disease damage.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Plots were rectangular in shape and designed to include approximately 64 planting spaces. The average plot size was approximately one-tenth of an acre.

Data collection began in 1975 with the measurement of 487 temporary plots in the lower coastal plain. There were 391 "select" plots and 96 "random" plots. Select plots were located in areas where stocking was uniform but not necessarily fully stocked. Random plots were randomly located within plantations.

In 1980, 336 monumented random plots were located in the lower coastal plain region, and 206 of these plots were remeasured in 1984. An additional 66 select plots were established in 1983.

In the upper coastal plain region, 56 select plots were established in 1981. Remeasurements were taken on 48 of these plots in 1985.

Basal Area Prediction and Projection, Survival Prediction, Height Projection

The stand table projection algorithm to be described later relies on accurate estimates of per-acre basal area and survival. Basal area prediction and projection equations were based on data from 457 select and 432 random sample plots with 206 remeasured random plots in the lower coastal plain. Data from 56 select plots with 48 remeasurements were used from the upper coastal plain region.

The general form of the basal area prediction equation was patterned after the Schumacher-type variable density yield equation

$$\ln Y = ß_0 + ß_1 \left(\frac{1}{A}\right) + ß_2 \, f(S) + ß_3 \, g(D)$$

where

Y = per-acre yield
A = stand age
f(S) = a function of site quality
g(D) = a function of stand density
(Pienaar and Shiver 1986).

For the lower coastal plain, basal area prediction and projection equations were derived from the combined select and random sample plot data.

$$\begin{aligned}\ln B = {} & -4.9198 - 14.8545\ (1/A) \\ & + 1.6005\ (\ln H) \\ & + 0.5208\ (\ln N) \\ & + 2.5499\ (\ln N/A) \qquad (1)\end{aligned}$$

$R^2 = 0.89 \qquad S_{y.x} = 0.04$

$$\begin{aligned}\ln B_2 = {} & \ln B_1 - 14.8545\ (1/A_2 - 1/A_1) \\ & + 1.6005\ (\ln H_2 - \ln H_1) \\ & + 0.5208\ (\ln N_2 - \ln N_1) \\ & + 2.5499\ (\ln N_2/A_2 - \ln N_1/A_1) \qquad (2)\end{aligned}$$

$R^2 = 0.89 \qquad S_{y.x} = 0.04$

where B, B_1, B_2 are basal area per acre in sq. ft at ages A, A_1, A_2 respectively, and H, H_1, H_2 the respective average height of dominants and codominants in ft, and N, N_1, N_2 the respective number of trees per acre.

The upper coastal plain equations are

$$\begin{aligned}\ln B = {} & -4.5290 + 1.4507\ (\ln H) \\ & + 0.5890\ (\ln N) \qquad (3)\end{aligned}$$

$R^2 = 0.87 \qquad S_{y.x} = 0.12$

$$\begin{aligned}\ln B_2 = {} & \ln B_1 + 1.4507\ (\ln H_2 - \ln H_1) \\ & + 0.5890(\ln N_2 - \ln N_1) \qquad (4)\end{aligned}$$

$R^2 = 0.88 \qquad S_{y.x} = 0.05.$

Parameters for the corresponding basal area prediction and projection equations were estimate simultaneously using the seemingly unrelated regression procedure with the restriction that corresponding parameters be the same (SAS 1986, ET Manual, Procedure SYSLIN).

The survival prediction equations were develope from 206 and 48 sample plots from the lower coast plain and upper coastal plain regions respectivel The general form of the equation is described by Pienaar and Shiver (1981). A modification was ma to include the effect of Cronartium infection on survival.

The lower coastal plain equation is

$$N_2 = N_1 \exp\left[-(0.0122 + 0.1997\ \mathrm{INF}) * \left((A_2/10)^{1.7877} - (A_1/10)^{1.7877}\right)\right] \qquad (5)$$

$S_{y.x} = 25.4 \qquad R^2 = 0.9$

where N_1 and N_2 are the number of trees per-acre at ages A_1 and A_2 respectively, and INF the percentage of trees with Cronartium stem infections as a decimal percent.

The upper coastal plain equation is

$$N_2 = N_1 \exp\left[-(0.0410 + 0.0696\ \mathrm{INF}) * \left((A_2/10)^{1.9936} - (A_1/10)^{1.9936}\right)\right] \qquad (6)$$

$R^2 = 0.68 \qquad S_{y.x} = 2.0$

The basal area projection equation requires an estimate of average height of dominants and codominants at the specified projection age. A projection equation for the average height of dominants and codominants was developed from the same remeasurement data used to derive the survival functions described above. A single equation was suitable for both the upper and lower coastal plain regions.

$$H_2 = H_1\{[1-\exp(-0.09091\ A\ )]/[1-\exp(-0.09091\ A\ )]\}^{1.8650} \qquad (7)$$

$$R^2 = 0.68 \qquad S_{y.x} = 2.0$$

where H_1 and H_2 are average heights of dominants and codominants at ages A_1 and A_2 respectively.

STAND TABLE PROJECTION

The stand table projection system is based on hypotheses concerning changes in trees' relative sizes over time. The relative size of the i^{th} tree is defined as $b_i/\bar{b}$ where b_i is the basal area of the i^{th} tree and $\bar{b}$ is the average basal area of all trees in a plot or stand. It is assumed that the change in relative size of a tree can be described by the equation

$$(b_{2i}/\bar{b}_2) = (b_{1i}/\bar{b}_1)^{(A_2/A_1)^{\beta}} \qquad (8)$$

where b_{1i} and b_{2i} are the basal areas of the i^{th} surviving tree at ages A_1 and A_2 respectively ($A_2 > A_1$), $\bar{b}_1$, and $\bar{b}_2$ are the average basal areas of survivors at ages A_1 and A_2, and β is a parameter to be estimated from remeasurement data. This equation reflects observed trends which indicate that trees less than average size tend to decrease in relative size while trees greater than average size tend to increase in relative size. Also, as initial age (A_1) increases, change in relative size decreases for a given projection period length.

A projected diameter list consistent with projected total basal area is obtained as follows

$$b_{2i} = \frac{B_2\ (b_{1i}/\bar{b}_1)^{\alpha}\ n_i}{\sum_{i=1}^{k} (b_{1i}/\bar{b}_1)^{\alpha}\ n_i} \qquad (9)$$

where $\alpha = (A_2/A_1)^{\beta}$, n_i is the number of surviving trees n the i^{th} initial dbh class ($i=1,2,\ldots,k$), b_{2i} is the projected future total basal area of these n_i survivors, and B_2 is the projected total basal area. This model construction insures that

$$\sum_{i=1}^{n} b_{2i} = b_2{*}n = B_2.$$

The β parameter estimates were based on 482 individual trees from 48 remeasured plots in the upper coastal plain, and on 2199 sample trees from 206 remeasured plots in the lower coastal plain. Parameter estimates for the two regions were not significantly different (α =.05), so the following common prediction equation was derived.

$$b_{2i} = \bar{b}_2\ (b_{1i}/\bar{b}_1)^{(A_2/A_1)^{0.05968}} \qquad (10)$$

$$R^2 = 0.94 \qquad S_{y.x} = 11\%$$

STAND TABLE PROJECTION APPLICATION

The stand table projection system will be illustrated for 15-year-old plantation. The distributions of trees with and without fusiform stem cankers are separately enumerated in Table 1.

Table 1. Distribution of infected and uninfected trees for stand table projection example.

Dbh Class	Total	Uninfected	Infected	Total
	trees/a	trees/a	trees/a	BA/a
2	1	1	0	0.0
3	11	6	5	0.5
4	45	27	18	3.9
5	103	70	33	14.0
6	140	89	51	27.5
7	107	80	27	28.6
8	38	27	11	13.3
9	5	4	1	2.3
Total	450	304	146	90

The plantation has an average dominant height of 45 ft. and a Cronartium infection rate of 32%. The projected stand variables at age 20 are:

$\hat{B}$ = 119 sq. ft./ac (eqtn. 2)

$\hat{N}$ = 404 trees/ac (eqtn. 5)

$\hat{H}$ = 56 ft (eqtn. 7).

Since the distributions of uninfected and infected trees are known, it is possible to identify the trees that will die in the stand table in a way which will reflect differential mortality rates for uninfected and infected trees.

First, the survival is calculated using the given infection rate in equation 5 (404 trees). Then, the survival is calculated using a 0% infection rate (442 trees). The number of uninfected trees expected to die during the projection interval is calculated as

$$M_U=(1-INF_1) * (N_1-N_{2,0}) = 5.2 \text{ trees/a}$$

Infected mortality is calculated as

$$M_I = (INF_1 * (N_1-N_{2,0})) + (N_{2,0}-N_{2,I}) = 40.5 \text{ trees/a}$$

where INF_1 = observed Cronartium infection rate (.32),

N_1 = initial trees/ac,

$N_{2,0}$ = predicted survival with 0% infection,

$N_{2,I}$ = predicted survival with infection rate equal to INF_1,

M_U = predicted mortality of uninfected trees,

M_I = predicted mortality of infected trees.

The infection rate at age 20 can then be calculated as

$$INF_2 = ((INF_1 * N_1) - M_I)/N_{2,I} = 26\%$$

The 5.2 uninfected trees and 40.5 infected trees are identified, based on relative size and relative frequency, as shown in Tables 2 and 3.

The future dbh class midpoint for the surviving trees in each diameter class is calculated using equation (9) with ß = 0.05968. A one-inch dbh class stand table is obtained by assuming that all trees in a given dbh class have the same growth and are evenly distributed in each class. The future dbh class limits are midway between predicted dbh class midpoints. The projected (age 20) stand table is shown in Table 4.

Table 2. Identification of uninfected mortality

Dbh Class	Trees/a (1)	$(\bar{b}/b_i)^2$ (2)	(3) (2)÷Σ(2)	(4) (1)÷Σ(1)	(5) (3)x(4)÷Σ(3)x(4)	Mortality (5)x5.2
2	1	84.211	0.763	0.003	0.135	0.7
3	6	16.634	0.150	0.020	0.160	0.8
4	27	5.236	0.048	0.089	0.228	1.2
5	70	2.156	0.020	0.230	0.242	1.2
6	89	1.040	0.009	0.293	0.148	0.8
7	80	0.561	0.005	0.263	0.072	0.4
8	27	0.329	0.003	0.089	0.014	0.1
9	4	0.205	0.002	0.013	0.001	0.0
Total	304	110.4	1.0	1.0	1.0	5.2

Table 3. Identification of infected mortality

Dbh Class	Trees/a (1)	$(\bar{b}/b_i)^2$ (2)	(3) (2)÷Σ(2)	(4) (1)÷Σ(1)	(5) (3)x(4)÷Σ(3)x(4)	Mortality (5)x40.5
3	5	16.634	0.635	0.034	0.123	5.0
4	18	5.263	0.201	0.124	0.431	17 4
5	33	2.156	0.082	0.226	0.222	9.0
6	51	1.040	0.040	0.349	0.165	6.7
7	27	0.561	0.021	0.185	0.047	1.9
8	11	0.329	0.013	0.075	0.011	0.5
9	1	0.205	0.008	0.007	0.001	0.0
Total	146	26.19	1.0	1.0	1.0	40.5

Table 4. Projected stand table at age 20.

Dbh-class	Trees/ac	BA/ac
4	11.2	1.0
5	38.2	5.2
6	77.7	15.3
7	110.8	29.6
8	91.0	31.8
9	52.6	23.2
10	20.1	11.0
11	3.3	2.2
Total	405	119.2

When observed stand tables were compared with projected stand tables, based on observed survival and basal area for all remeasured plots, none of the projected stand tables differed significantly from observed stand tables based on a Kolmogorov-Smirnov test (α=.05).

SUMMARY

Management inventory systems in the Southeast often include a tally of trees by one-inch diameter classes. The stand table projection method described here makes efficient use of this type of inventory information because no assumptions about underlying probability distributions are made. The system is dependent on reliable estimates of future per acre basal area and survival. If the distributions of trees with and without fusiform stem cankers are known, it is possible to account for differential mortality rates for infected and uninfected trees.

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INTRODUCTION TO THE "COMPUTE" SERIES OF GROWTH AND YIELD PREDICTION SYSTEMS FOR ARTIFICIALLY REGENERATED SOUTHERN PINES[1]

V. C. Baldwin, Jr. and R. B. Ferguson[2]

Abstract.--Comprehensive Outlook for Managed Pines Using simulated Treatment Experiments (COMPUTE) is an acronym describing a series of growth and yield prediction systems for artificially regenerated southern pines in the West Gulf region. COMPUTE_P-LOB and COMPUTE-MERCHLOB, two published prediction systems in this series, are for use with thinned and unthinned plantations of loblolly pine. COMPUTE_P-SLASH, for growth and yield predictions of thinned and unthinned slash pine plantations, and COMPUTE_DS-SLASH, for predictions of unthinned or precommercially thinned stands of direct-seeded slash pine will soon be available also. An overview of these prediction systems is given in this paper, including general input requirements, modeling procedures utilized, and various output options that may be selected.

INTRODUCTION

Over 2 million acres of forestland are planted or seeded to pine in the south each year to replace the annual harvest and to convert low-valued hardwood or agricultural sites to pine. Increasingly, forest managers depend on predicted forest yields to help set management strategies and convince investors as to the merits of making substantial long-term investments. The competitiveness for investment capital demands strong credibility in the decision analysis and the data supporting the analysis.

Growth and yield prediction systems and accompanying computer programs have recently been developed at the USDA Forest Service Southern Forest Experiment Station for both planted loblolly pine and planted or direct-seeded slash pine in the West Gulf Region. Direct-seeding is herein defined to mean seeding by any non-natural means. Publications describing the loblolly pine system have already been released (Baldwin and Busby 1988, Baldwin and Feduccia 1987, Ferguson and Baldwin 1987, 1988); those for the slash pine systems are in the process of being completed.

All of these prediction systems have been developed in a similar fashion utilizing variations of the Weibull parameter recovery-diameter distribution-whole stand projection modeling technique proposed earlier in this decade (Hyink and Moser 1983, Matney and Sullivan 1982). This technique utilizes equations that model changes over time in commonly measured stand attributes such as mean diameter, basal area, dominant and codominant height, and number of trees per unit area. Percentile diameters (the diameter at which a set percent of the trees have smaller diameters) are also used in the modeling process.

The predicted information is used to estimate a specific Weibull distribution--a function that has been shown to be a very useful model of diameter distribution in even-aged stands. Because of the technique similarities, it was decided that one computer program framework would be used for all of these prediction systems, and they would be released as a series. This action requires users to become familiar with the operation of just one program utilizing essentially the same program instructions, input requirements, and similarly formatted output. The emphasis of the program has been on the ease of use and a variety of output options designed for the user.

The series is called: Comprehensive Outlook for Managed Pines Using simulated Treatment Experiments (COMPUTE). The name is suffixed by a term describing the applicable species (for example, P-LOB for planted loblolly pine) or a term describing both species and an added processor that improves base-line predictions for certain conditions (such as MERCHLOB for planted loblolly pine predictions run through a merchandising optimizer).

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[1] Paper presented at Southern Silviculture Research Conference, Memphis, TN, November 1-3, 1988.

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Our objective in this paper is to describe the COMPUTE series of computer programs. COMPUTE_P-LOB has been released for nearly a year. Prototypes of the COMPUTE_MERCHLOB and COMPUTE_DS-SLASH programs are available for release at this time to those individuals who are willing to help us test these programs. COMPUTE_P-SLASH, and publications for the slash pine prediction systems, which will provide specifics about the models and techniques utilized, the data sets, and fit statistics, should be available soon.

PROGRAM DESCRIPTION

General Information

With one exception, the COMPUTE programs are written for interactive mode processing. Normal program operation involves responding to a set of questions keyed to the user's particular situation. Some questions require multiple responses.

COMPUTE programs assume one of three general situations: (1) starting and ending with an unthinned stand; (2) starting with an unthinned stand, thinning at some age, and ending with a stand thinned a variable number of times; or (3) starting with a previously thinned stand and ending with a stand thinned a variable number of times. In this paper, thinning refers to commercial or some later thinning, as opposed to precommercial or early thinning, unless otherwise indicated. These situations, the required initial values, and the prediction process are summarized schematically in figure 1. The abbreviations used in the figure, and henceforth in this paper, are: A (stand age), HD (mean height of the dominant and codominant stand component), SI (site index), TS (trees surviving per acre), BA (basal area per acre), DBH (diameter at breast height), DMIN (minimum diameter), QMD (quadratic mean diameter), P93 (diameter of the 93rd percentile), and TP (trees planted per acre).

Required input information when starting with an initially unthinned stand includes A, HD, and TS. If HD or TS is unknown, then SI, BA, or TP are input variables that can be substituted for the required site and density measurements.

When starting with a previously thinned stand, the system requires A, HD, and TS. As in the unthinned case, an estimate of SI can be substituted for HD. Furthermore, if an estimate of TS is not known, it can be predicted by providing the stand age and the residual trees surviving at the time of the last thinning. The user may then simulate practically unlimited no-thinning or thinning trials by varying residual densities, thinning cycle lengths, and rotation ages within the prediction limits described for each system.

Output yields are either in volume- or weight-per-acre. The user may select cubic-foot volume inside bark (ib) and outside bark (ob) outputs to three optional top diameter limits to assist in merchandising the stand. Board-foot volume yields are output for either the Doyle, Scribner, or International 1/4-inch rules. Green or dry weight yields are presented for total bole (ib and ob), bole to one top diameter limit (ib or ob), branches (ib or ob), and foliage.

The program can produce up to 15 stand/stock tables per run in either a detailed or summarized format for volume, dry weight, or green weight. The user also has the option of printing cut tables when thinning as a quick reference of what the model has removed from the stand by thinning. The cut tables do not count against the number of stand tables.

Specific Information

COMPUTE_P-LOB and COMPUTE_P-SLASH.--Growth and Yield predictions may be made in thinned or unthinned stands, aged 10 to 50, established on essentially problem-free sites. Growth projections are based on 5-year growth intervals, but projections can be made over any length of time.

COMPUTE_DS-SLASH.--The user initially determines if his stand fits one of the folowing categories: (1) broadcast-seeded and unthinned, (2) broadcast-seeded and selectively precommercially thinned, (3) broadcast-seeded and precommercially row-thinned, or (4) row-seeded and unthinned. Separate growth and yield prediction equations were fitted to the data from each of these categories. No commercial thinnings are allowed, and predictions can be made for stands 5 to 25 years old. In the case of precommercially thinned stands, projections may begin no earlier than immediately following the thinning.

COMPUTE_MERCHLOB.--This loblolly pine prediction system[3] utilizes product pricing and merchandising information, as well as growth and yield information, input by the user, to grow the stand managed in the manner prescribed. The predicted stand/stock tables are then converted into an estimated product mix by using a dynamic programming algorithm that maximizes the selling value of the stand. The model allows the user to specify up to six different products: (1) poles, (2) veneer, (3) sawtimber, (4) chip-n-saw, (5) pulpwood, and (6) chips. Residual wood is used if the chips category is not used because the model requires that the entire bole of the tree be accounted for. The units of measure for each product may be: tons, cords, Doyle, Scribner, or International 1/4-inch board feet, depending upon the type of product being produced.

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[3] Although a paper describing this system has already been published (Baldwin and Busby 1988), it should be noted that the merchandising optimization subroutine was based on a program conceptualized and first written by Keith B. Ward. This earlier work, which will be reported in "MERCHOP: A dynamic programming model for estimating the harvest value of unthinned loblolly and slash pine stands" by Rodney L. Busby and Keith B. Ward, is in review.

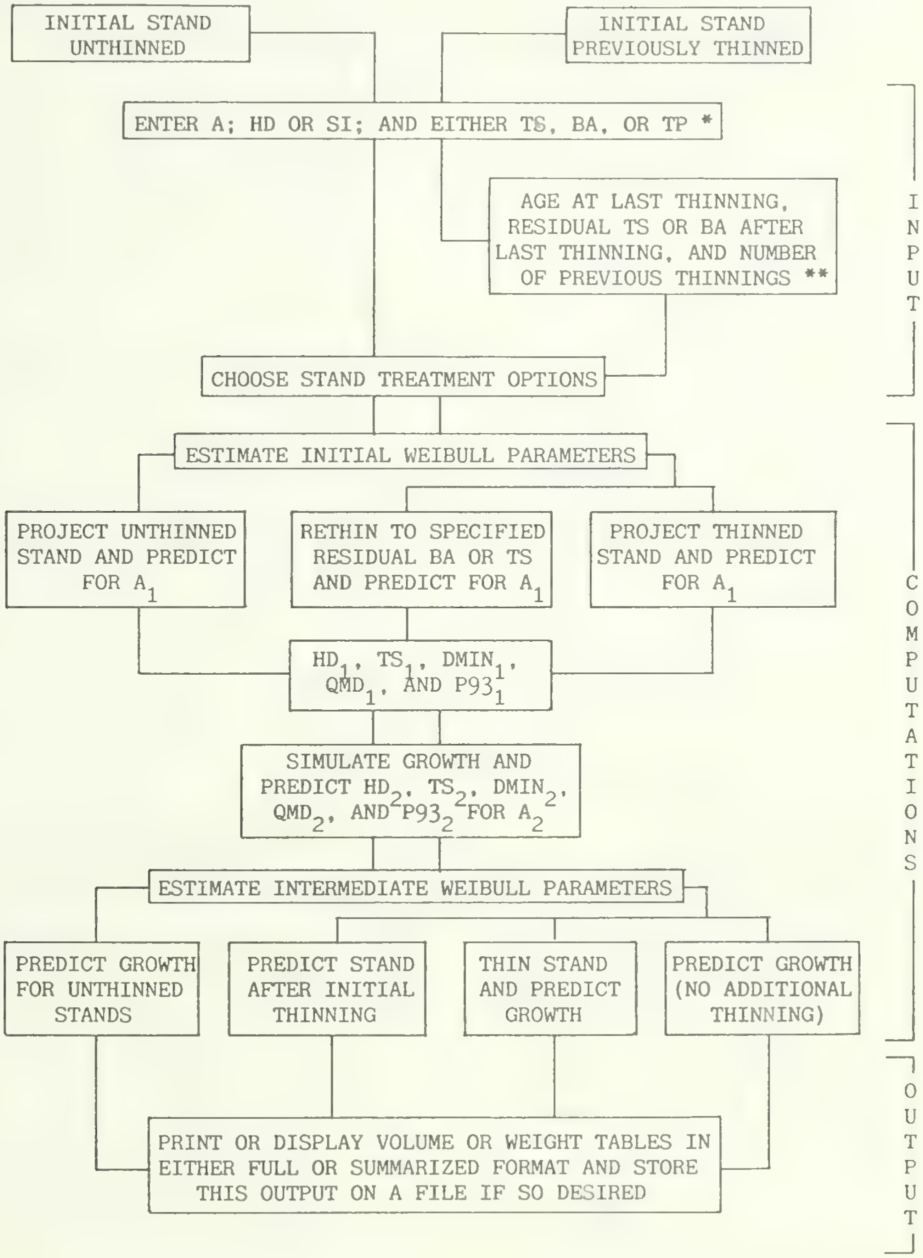
INITIAL STAND UNTHINNED
INITIAL STAND PREVIOUSLY THINNED
ENTER A; HD OR SI; AND EITHER TS, BA, OR TP *
AGE AT LAST THINNING, RESIDUAL TS OR BA AFTER LAST THINNING, AND NUMBER OF PREVIOUS THINNINGS **
CHOOSE STAND TREATMENT OPTIONS
INPUT
ESTIMATE INITIAL WEIBULL PARAMETERS
PROJECT UNTHINNED STAND AND PREDICT FOR A_1
RETHIN TO SPECIFIED RESIDUAL BA OR TS AND PREDICT FOR A_1
PROJECT THINNED STAND AND PREDICT FOR A_1
HD_1, TS_1, $DMIN_1$, QMD_1, AND $P93_1$
SIMULATE GROWTH AND PREDICT HD_2, TS_2, $DMIN_2$, QMD_2, AND $P93_2$ FOR A_2
ESTIMATE INTERMEDIATE WEIBULL PARAMETERS
PREDICT GROWTH FOR UNTHINNED STANDS
PREDICT STAND AFTER INITIAL THINNING
THIN STAND AND PREDICT GROWTH
PREDICT GROWTH (NO ADDITIONAL THINNING)
COMPUTATIONS
PRINT OR DISPLAY VOLUME OR WEIGHT TABLES IN EITHER FULL OR SUMMARIZED FORMAT AND STORE THIS OUTPUT ON A FILE IF SO DESIRED
OUTPUT

Figure 1. Generalized schematic representation of the loblolly pine growth and yield prediction system COMPUTE_P-LOB (* denotes initial inputs required for all stands, ** denotes inputs required only when starting with a previously thinned stand). Meanings of abbreviations are given in the text.

Price and product dimensions must next be specified. Price per unit by product, minimum and maximum top-end diameters, minimum and maximum piece lengths, the piece length increment, and allowance for trim must be specified. These inputs allow the user to specify the size and value for each product. For example, the user could say that poles must have a top-end diameter between 4 and 10 inches and be between 40 and 70 feet in length. Note that the user is asked only to define possible products. The problem of how to best allocate the production of the various products will be solved by the model.

Two problems arise when attempting to estimate the value of projected stands based on growth and yield models: (1) form and disease product degrade information are not provided, and (2) small quantities of even high-valued products may be too expensive to sort out and sell. Form and disease product degrade may be modeled by inclusion of the input variable NPRCNT, defined as the maximum percentage of properly sized trees that are suitable to make a product such as poles or veneer logs. For example, not all trees 40 feet in height measured to a 6-inch top are suitable for pole production because some may have bad form or disease-induced degrade. Therefore, the user can set NPRCNT to, say, 10 percent if it is presumed that only 10 percent of such trees might be suitable for pole production. The purpose of NPRCNT is to allow the user to simulate the effects of defects. The estimate of the value of a stand will be too high if the form and disease product degrade is ignored. Thus, NPRCNT must be set for each product, and it must range between zero and 100 percent.

The final input variable, HARVST, sets the minimum harvest necessary for any product to be produced. A timber stand may contain low volumes of a high-valued product, but that product might not be economical to produce because of high sorting costs. For example, the user may specify that a minimum of 1,000 board feet per acre of sawtimber must be produced if the product is to be produced at all. This procedure allows the user to model the effects of sorting costs without having to include extensive logging and sorting cost information into the model. This program is set up to run in a batch mode because of the much greater amount of input information required.

An Example

As an example, to illustrate how the user can respond to prompts in COMPUTE programs, let us consider a 15-year-old loblolly pine plantation with a site index of 60 feet (base age 25) and 500 trees surviving per acre. We want to know the stand volume for merchantablity limits of 0-, 4-, and 8-inch top diameters. The following reproduces the program display as seen by the user. The brackets [ ] are used to indicate the user's responses--they are not to be used as part of the response--and are included as part of the example.

SCREEN DISPLAY:

```
  Choose your output device
     S = Screen output
     H = Hardcopy printer
[S]
     Enter a label for your output (60
     characters or less)

[EXAMPLE OUTPUT]

     Describe the stand by answering the
  following questions.  Enter a zero (0) if you
  do not know the answer to a question requiring
  a numeric response.  Use the designated
  character responses where indicated.  Certain
  questions have a preset default response
  (indicated by an asterisk (*) following the
  default).  If you accept the default, press
  the RETURN key.

     At the very least you must provide STAND
  AGE, a measure of DOM/CODOM HEIGHT, and a
  measure of STAND DENSITY.  If you are starting
  with the closing values of a previous run of
  the model, the answers must come from that
  output in order to set up the new run.

     Are you starting with the closing values
  for a previous run of this program?
        Y = Yes
        N = No (*)
[N]
     Stand age?
[15]
     Height of dominants and codominants?
[0]
     Site index?
[60]
     Site index base age?
[25]

     Surviving trees per acre?
[500]
     Has this stand been thinned before?
        Y = Yes
        N = No (*)
[N]
     Are your initial stand inputs entered
  correctly?
        Y = Yes (*)
        N = No
[Y]
     How many new thinnings? -- (Must be less
  than or equal to 10)
[0]
     Choose form of output:
        V = Volume (*)
        G = Green weight
        D = Dry weight
[V]
     Enter three top diameter limits for volume
  tables (0=total volume).
        (Example: 0,4,8 for total volume, volume
        to a 4-inch top, and volume to an 8-inch
        top, respectively.)
[0,4,8]
```

```
    Do you want a single table per page or
  continuous output?
        S = Single table per page
        C = Continuous feed (*)
[C]
    Choose form of output tables:
        F = Full tables (*)
        S = Summary tables
[F]
    Choose a board-foot volume rule:
        I = International 1/4-inch (*)
        S = Scribner
        D = Doyle
[I]
    Number of stand tables (do not include any
    cut tables in your count)?  NOTE: You must
    run the before-thin situation at a given
    age before you can run the after-thin.
[1]
    For each stand table requested enter the
  age and the thinning code:

        N = No thinning
        B = Before thinning
        A = After thinning
           (Example of input: 10,N; for age 10,
           no-thin table)

    For stand table #1, enter age and thinning
  code.
[15,N]
    Are your stand table specifications
  correct?
        Y = Yes (*)
        N = No
[Y]
```

```
    Please wait.  Your request is being
  processed.  (After all tables have been
  produced as output the user will be asked
  about storing the output on a disk file.  If
  you want to store this information you must
  specify a proper file name and storage device
  as required by your system.)

    Do you want to save your output on a disk
  file?
        Y = Yes
        N = No (*)
[N]
    Do you want to continue?
        Y = Yes (*)
        N = No
[N]
    (This response will cause the program to
  terminate.)
```

The results of this example are presented in figure 2.

PROGRAM AVAILABILITY

The COMPUTE_P-LOB program is currently available in FORTRAN-77 (compiled and source code versions) for the IBM-PC compatable systems with the Microsoft DOS 2.10, the Data General MV/X000 series, and Digital Equipment Corporation's PDP/11 and VAX series computers. A BASIC version is also available for the IBM-PC.

```
                          LOBLOLLY PINE
                     NO THINNING THIS YEAR
                           (PER ACRE)

   AGE=   15
   DOMINANT HEIGHT= 44.5 FEET
   QUADRATIC MEAN DBH=  6.337 INCHES
=============================================================================
                                CUBIC FOOT VOLUME OF STEMS          INTER.1/4
 DBH  STEMS BASAL AV.           TO AN O.B. TOP DIAMETER OF          B.F. VOL.
CLASS       AREA  HT.     0 INCHES       4 INCHES       8 INCHES    8-IN. TOP
            sq.         ------------   ------------   ------------
 in.    no.  ft.  ft.   o.b.     i.b.   o.b.     i.b.   o.b.    i.b.     i.b.
-----------------------------------------------------------------------------

  2      1   0.0  19      0.       0.     0.       0.     0.      0.       0.
  3     16   0.8  28     12.       8.     0.       0.     0.      0.       0.
  4     54   4.7  35     88.      63.     0.       0.     0.      0.       0.
  5    101  13.8  39    281.     204.   184.     129.     0.      0.       0.
  6    129  25.3  42    546.     403.   456.     332.     0.      0.       0.
  7    110  29.4  44    653.     488.   599.     444.     0.      0.       0.
  8     62  21.6  46    496.     374.   474.     355.     0.      0.       0.
  9     22   9.7  47    225.     170.   219.     165.    97.     69.       0.
 10      5   2.7  48     64.      48.    63.      48.    38.     28.     151.
-----------------------------------------------------------------------------
       500 108.1       2365.    1758.  1995.    1473.   135.     97.     151.
=============================================================================
  SI(BASE AGE  25)=  60 FEET;  93RD PERCENTILE=  8.353
  WEIBULL PARAMETERS:  "A"=  1.703;  "B"=  4.969;  "C"=  3.359
```

Figure 2. Example of program output for the volume option.

FUTURE PLANS

Work is also being done on growth and yield prediction systems for thinned and unthinned planted longleaf pine and for rust infected plantations of loblolly and slash pine. It is anticipated these systems will also be programmed to be used with and released as part of the COMPUTE series. Furthermore, it is our intent to produce a merchandising optimization version of all the growth and yield prediction systems for each species.

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PREDICTING GROWTH FOR MIXED PINE-HARDWOOD STANDS - APPROACHES, PROBLEMS, and FUTURE[1]

Roger K. Bolton and Ralph S. Meldahl[2]

Abstract: In recent years, increased attention has been given to the management of mixed pine-hardwood stands. Consequently the prediction of growth and yield for these stands is also receiving increased attention. In the last decade, several attempts have been made at developing an individual tree projection system for this resource. Several formidable barriers have made the development of these systems very difficult. These issues are discussed so future work can be focused in the most advantageous direction and hopefully avoid the pitfalls of the past.

INTRODUCTION

In the past, growth and yield studies in the South have concentrated on pine plantations. This has created a paucity of information for the other 75 percent of forestland found in the South. In turn, an extensive resource has been neglected. However, as more demands are placed on the forestland resource, increased attention has been directed toward the management of the pine-hardwood type. This trend is particularly noticeable in isolated regions of the South, such as southwest Alabama. Furthermore, as financial constraints increase, alternatives to cost-intensive pine plantations are being sought. Therefore, it is no longer a question of whether there is a need for such models, but what is the best way to make predictions for such a diverse forest type.

At Auburn University, efforts have been underway since the early 1980's to predict tree growth in mixed pine-hardwood stands throughout the South. Work has focused on distance-independent individual tree models. Several different projection systems have been derived over the years. Some of the earlier work included projection systems, for various members of forest industry, in North and South Carolina and in central Alabama. A system was also derived in cooperation with the U.S. Southern Forest Experiment Station to predict growth of trees on Forest Survey plots. These projects lead to the development of a projection system for the state of Georgia (Bolton and Meldahl 1988). Current efforts are concentrating on a projection system for Alabama, Georgia, and South Carolina (Meldahl et al. 1988). Efforts have dealt primarily with model building rather than on deriving the computer framework.

Whenever possible ideas were sought from other projects. Other individual tree projection systems which have been quite helpful have been PTAEDA (Burkhart et al. 1987), G_HAT (Harrison et al. 1986), Prognosis (Wykoff et al. 1982), CACTOS (Wensel and Biging 1988), TWIGS (Belcher 1982) and N.E. TWIGS (Hilt and Teck 1988). Some of the more recent work in diameter distributions for this forest type is also very encouraging (Jayaraman 1987, Yandle et al. 1988).

Over the years much has been learned about modeling mixed pine-hardwood stands. New methodologies and techniques are developed with each new system. Models have also increased in both breadth and depth. Along the way, changes in computer technology have made results easier to implement and to be used by the field forester. Due to the recent surge of interest in mixed stands, this paper will discuss some of the hurdles which had to be overcome and opportunities for future research.

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OBSTACLES

The largest obstacle has been the lack of a truly good database. Data used to build individual tree models are difficult to obtain due to the expense and time involved in data collection. Likewise, funding to collect data of this nature is usually scarce. Meanwhile a very real demand for answers exists and must be meet. To satisfy this need, our modeling attempts have utilized U.S.D.A. Forest Service Forest Survey (FIA) data or a company's Continuous Forest Inventory (CFI) data. These data can be used to detect and measure diameter growth fairly well. However, using such data carries a host of problems.

The biggest problem with using FIA or CFI data is that they were not collected for growth studies. Much of this data is collected to detect regional trends, and therefore uses a sample design which is not optimal for growth studies. This results in a deficiency on the extremes of the data and restricts model development to the "average" stand, or what has been labeled the "globular effect" (Hilt 1988). An additional shortcoming is that although data from different Surveys are usually similar, very seldom are they compatible enough to combine and to fill the needed data matrix. Also this type of data does not always possess the desired information or in the form needed. For example, Survey data will present stand conditions for two points in time. However, the stand history is never fully known, thereby confounding many unknown factors. In addition, some key variables are defined such that they are deemed not very "valuable" (i.e. stand age and site quality). Lastly, the time between measurements is usually too long to accurately measure mortality. These weaknesses are not viewed as severe enough to preclude the use of these data. Furthermore, no other data have been found which cover the numerous growing conditions found throughout the South. Most of these problems can be dealt with and solved.

Some of the problems which exist with Survey data are reflections of current mensurational problems. Consider such influential factors as site index and stand age. Most studies have concluded that stand age is one of the most important variables influencing growth. Unfortunately, an acceptable method of measuring stand age in uneven aged stands has never been agreed upon. Plus, every Survey or CFI seems to collect age differently in the uneven aged conditions. Therefore, stand age was not always used in the analysis. These problems with stand age are further compounded when using site index.

Site index has traditionally been used to measure site quality. It is common knowledge that using site index to measure site quality is less than perfect. Avery (1975) listed the following limitations of site index.

"1. Stand age is difficult to determine, and small errors can cause relatively large changes in the site index value.
2. The concept of site index is not well suited for uneven-aged stands, areas of mixed species composition, or non-forested lands.
3. The total effects of stand density are not considered in deriving site index curves.
4. Site index is not a constant; instead it may change due to environmental and climatic factors.
5. The site index value for one species can not generally be translated into a usable index for a different species on the same site."

These limitations are generally ignored and site index is applied as a representation of site quality. This works well until site index is used in growth modeling. In an attempt to circumvent these problems, FIA Surveys collect site quality information based on the cubic foot/acre potential yield of a stand. For the purposes of our projection systems, these site classes however must be "converted" to site index. The result has been a number which is only able to insure that a site index of 100 is better than a site index of 50, and thus has very little biological meaning. This makes it difficult to use such a figure in building biologically based growth models.

APPROACHES

In every projection system which has been derived at Auburn University, modeling efforts have gone through five steps; data manipulation, model building, model implementation, and model validation.

The first step of data manipulation usually involves extensive programming to become familiar with the data and to calculate needed variables. This step is where many of the obstacles previously discussed are discovered. Generally this step requires a considerable amount of time programming in a higher level computer language, i.e. FORTRAN, Pl/I, C.

Before modeling efforts were begun, our analyses made three assumptions regarding tree growth. All of these assumptions may be argued; they seem however to provide a reasonable representation of tree and stand growth. The first assumption was that different species may grow differently on the same site, e.g., loblolly pine versus sweetgum on the same site. This assumption was relatively straightforward and intuitively obvious. It was for this reason, along with the complex structure of natural stands, the inherent flexibility of individual tree models, and the success that other regions of the country have had, that efforts have concentrated on distance independent individual tree models.

The next two assumptions essentially dealt with further isolating the site. The second assumption was that individual species may grow differently in the different physiographic egions, e.g., loblolly pine in the ridge and alley versus loblolly pine in the lower coastal lain, given identical stand conditions (age, ite, density, etc.). The last assumption is hat an individual tree may grow differently in ifferent forest types, e.g., loblolly pine in he oak-pine forest types versus loblolly pine in he loblolly pine forest type, given identical tand conditions (age, site, density, etc.).

These assumptions also created several new bstacles. They created problems because the lassification of a site into physiographic egions and forest types tends to be very ubjective. For example, at least four ifferent but similar ways of dividing Georgia nto physiographic regions were found in the iterature. This subjectivity is further agnified when dealing with forest types. lassifications must also be compatible with the ata, which is not always possible. A lassification scheme can only be used if those ariable used in the scheme were collected in the urvey. Secondly, these assumptions imply that ifferent species will interact and compete ifferently on the same site. However, research tudying intra-species competition is just eginning. Therefore, this interaction was not odeled, but considered to be an inherent factor n all models. Lastly, all these assumptions esulted in a rather large multidimensional data atrix (physiographic region, forest type, pecies, etc.). It was not desirable or ractical to develop models for all cells within his matrix. Therefore, a clustering algorithm as used to group like cells of the large matrix ogether. This heuristic algorithm has been reviously discussed (Meldahl et al. 1984). It, owever, further adds complexity to what is lready an abstruse system.

Model building can sometimes be the easiest art in developing a growth projection system. his is not only because so many obstacles have lready been overcome, but also because the data o not deserve intensive scrutiny. For example, onsider the "globular effect" again. Many ethods can be used to derive prediction quations: multiple linear regression, non-linear egression, logistic regression. However, even he most sophisticated analysis will only produce arginal results in those cells where data are acking. Nevertheless, this real demand for nswers exist. Modeling efforts therefore ontinue and efforts are exerted to move away rom empirically derived models to more iologically based models.

The next step in model building is usually odel implementation. This is the stage where rowth and mortality models are put into a ramework so they can actually be used in the real" world. This step is not as simple as it nitially seems. First, there is the problem of cquiring or designing a computer framework. his is accompanied by the selection of volume quations, which are difficult to match with the onditions for which the system was designed. hen, of course, comes the programming required o make the system work. In this day and age of sophisticated, relatively inexpensive, and abundant software we tend to overlook the considerable amount of work involved in programming. Lastly, manuals must be written describing system use and design. This all results in more work than the researchers typically anticipated when they started. Furthermore, the reward system for many scientists, especially in academia, does not motivate a thorough job in this crucial step.

The last step in model building is validation. Deadlines and lack of funding can delay this step indefinitely. Burk (1986) listed three reasons why modelers avoid model validation.

"- Relatively little literature exists to guide researchers in the appropriate statistical approach.
- Statistical validation in its purest form requires setting aside of data or obtaining independent data.
- Validation is one of the least glamorous aspects of modeling and contributes little to the acceptance of work in refereed outlets."

The model validation we have done has been most beneficial. It has installed confidence in our modeling efforts, isolated the strengths and weakness of our past efforts, and will allow us to concentrate our future efforts.

FUTURE

By the time a projection system is finished, a modeler usually would like to start again from scratch. However, the demand for answers, and usually publications, exists. Thus, a wish list of future projects is generated so that next time the project is tackled it is done "right".

The greatest need for future efforts is an adequate database. These data can be derived from a set of permanent plots established in varied forest conditions. Such a network of plots would allow detailed study of the problems delineated earlier. The need for such long term studies is also recognized in related subjects like acid deposition. However, this system would be expensive. To reduce the cost, plots could possibly be constructed in conjunction with many of the permanent plots already established in Surveys and CFIs. These plots should allow the detailed study of tree and plot variables which a normal Survey cannot justify. Many of the problems which were discussed earlier could be researched on these plots. The problems of site quality and classification could easily be studied on such a designed system. Also, these plots would allow for the study of intra-species competition and interactions.

Scientists other than just biometricians should be involved in this study. Future growth models will be more process oriented and exhibit much more bio-logic. The easiest way to become more process oriented is to incorporate the varied disciplines in both data collection and analysis. Interdisciplinary efforts could also help in the study of site quality and site classifications. Many schemes have been designed to estimate both of these parameters, but very few of them have really been accepted in the "field". Advancing to more general and less restrictive parameters than what is currently available will take the cooperation of soil scientists, biologists, silviculturists, and biometricians.

This does not mean that no "true" biometrical type work exists to be done. On the contrary, there is probably to much work for too few people. Some foreseeable projects include the following:

1. Model validation should become a top priority. This step in model building has become crucial. Therefore, many of the barriers to conducting validation are being removed. One big reason for this has been the increase in research that is being conducted and published in this area. Only by conducting model validation will we be able to advance to the next level of growth modeling.

2. Error propagation in growth projection systems should be studied. It is known that a given growth model contains errors. However, when different models are connected in a projection system it is not know how errors interact and accumulate. Such studies can help channel efforts in the most appropriate direction. For example, Gertner (1988) found in an error propagation study that the most variability in his projection system was derived from predicting mortality. Therefore, the best way to improve his predictions will be to concentrate efforts on mortality. A similar study with our current efforts would be most interesting, because mortality is probably the weakest part of our projection systems, due to the nature of the data. If similar results are obtained, the need for a better mortality database would be essential to future efforts.

3. Another study which would be very beneficial is the prediction of natural reproduction in a stand or ongrowth. In uneven aged stands, it is known that reproduction occurs within the stand. This event should be modeled for the same reasons as mortality. Without this component, an essential aspect of tree and stand growth is neglected. When making long term projections, this process would seem to be extremely important.

4. The prediction of tree quality is another important project. As a tree grows it may change in quality from being classed as pulpwood, to high quality sawlog, back to pulpwood, and then to rough and rotten before it dies. Therefore, for accurate volume predictions and economic analysis this change should be modeled. Here, again, the idea that what is being modeled is a process is important.

5. Research could be started on modeling the different ecosystems and regions of the South which have been neglected. For example, projections systems for either the Mississippi Delta or West Gulf region are not abundant. Also, it may be more advantageous, once a site classification scheme is derived, to model by unique forest conditions, e.g. a swamp, rather than by regions.

6. Lastly, certain philosophical issues need to be addressed. For example, how accurate do our predictions really need to be, especially when the input comes from samples with known errors? How much is it worth to improve our predictions by a given percentage? Based on these answers, how "good" does the data to model growth need to be to solve management problems?

To solve many of these problems, new areas of study will have to be explored. These new subjects are what make research exciting. For example, the uses of artificial intelligence and non-parametric statistics have barely been touched. As scientists we must continue to learn from our colleagues in other fields of study.

SUMMARY

Growth and yield modeling has developed rapidly in the last several years. These advances are due in part to the availability of high-speed computers, and significant progress in the fields of mathematics and statistics. These new "tools" have been instrumental in solving many problems. Within the last 10 years at Auburn University, growth modeling has gone from simple linear models derived and implemented on a large obtrusive mainframe computer to more biologically based models which interact at more friendly levels on a desk top computer. Along the way there have been many obstacles to overcome. Some of which, like site index and site classification, neither time nor funds allowed us to study in detail. These problems will not go away though and only through better data and inter-disciplinary studies will they be solved.

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LOBLOLLY PINE SEED SOURCES DIFFER IN STEM FORM[1]

R. C. Schmidtling[2] and A. Clark, III[3]

Abstract.--The loblolly pine planting in the Southwide Southern Pine Seed Source Study in southwest Georgia was sampled at 35 years of age. Felled-tree dendrometric measurements were collected from 204 trees of 9 provenances. Regressions of actual volume on D^2H revealed significant seed source differences. The slope of the volume prediction equation for the Livingston Parish, LA, source differed from that of the other eight seed sources. That is, for trees of the same height and diameter, those from Livingston Parish have the least volume because of different stem form. Despite this difference, the Livingston Parish source ranked first in volume per acre because of greater growth rate.

INTRODUCTION

Provenance variation in loblolly pine is xtensive (Wells and Wakeley 1966). This ariation has been utilized by moving seed ources in two directions: westward from oastal Carolina to Arkansas to obtain faster rowth (Lambeth and others 1984) and eastward rom Livingston Parish, Louisiana (LPL), to btain better survival in areas of high usiform rust occurrence (Wells 1985). ains in growth and survival are well ocumented, and there are also apparent rovenance differences in stand size/density elationships (Schmidtling 1988).

Amateis and Burkhart (1987) have documented ifferences in tree volume and taper by stand rigin. The objective of the study described erein was to determine whether there are ifferences in stem form among provenances, and f so, what effect these would have in etermining final yield.

DATA

Large-plot, long-term genetic studies for esting variation in growth and yield are relatively rare. The Southwide Southern Pine Seed Source Study (Wells and Wakeley 1966) provides one of the best opportunities for this type of testing. Data from one of these plantings, in Dooly County, Georgia, were used for this study.

The planting was established in 1952-53 with planting stock from nine provenances (table 1). A randomized complete-block design with four replications was used for the planting. Each replication of each provenance consists of a square, 121-tree plot, with 72 trees in border rows and 49 periodically remeasured interior trees. Spacing was 6 - by 6-feet. Complete details of the Southwide study can be found in Wells and Wakeley (1966).

Measurements of total height and stem diameter at 4.5 feet (d.b.h.) at age 35 years were used for the present analysis. In addition, three to nine trees per plot were felled for stem measurements. Stump diameter and outside bark diameters at 5-foot intervals, starting at 10 feet above the ground, were measured. Volumes for the felled trees were computed using Smalian's formula.

ANALYSES

Volume, height/d.b.h., tree form, and taper relationships were examined following the procedures of Amateis and Burkhart (1987). Regression and covariance methods of Neter and Wasserman (1974) were used to test provenance differences in slope and intercept.

Total Volume

Regressions for predicting volume using $(\text{d.b.h.})^2 * \text{height}$ were computed using several models. Differences in slope of the fitted regression lines by provenance were tested by comparing the full model:

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[1] Paper presented at Fifth Biennial Southern ilvicultural Research Conference, Memphis, TN, ovember 1-3, 1988.

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Table 1.--Location of seed sources and stand characteristics for a 35-year-old loblolly pine provenance test in south Georgia

Provenance					
Symbol	Region	County	No. trees/ acre	Mean height (ft)	Volume (ft^3/ acre)
MD	Eastern Maryland	Somerset	506	67.3	5,788
NC	Southeastern N. Carolina	Onslow	451	67.1	5,475
NC	Eastern N. Carolina	Pamlico	488	66.9	5,651
GA	Southwestern Georgia	Wilcox and Crisp	469	65.4	5,529
AL	Northern Alabama	Cullman	475	63.2	5,179
AL	Northern Alabama	Jefferson	464	63.6	4,589
LPL	Southeastern Louisiana	Livingston	469	66.8	5,937
TX	East Texas	Angelina	500	64.4	5,616
AR	Southwestern Arkansas	Clark	494	62.9	4,972

$$\begin{aligned} Y_i = {} & B_o + B_1X_{i1} + B_2X_{i2} + B_3X_{i3} + B_4X_{i4} + B_5X_{i5} + \\ & B_6X_{i6} + B_7X_{i7} + \\ & B_8X_{i8} + B_9B_{i9} + B_{12}X_{i1}X_{i2} + B_{13}X_{i1}X_{i3} + B_{14}X_{i1}X_{i4} \\ & + B_{15}X_{i1}X_{i5} + B_{16}X_{i1}X_{i6} + B_{17}X_{i1}X_{i7} + B_{18}X_{i1}X_{i8} \\ & + B_{19}X_{i1}X_{i9} + E_i \ , \end{aligned} \tag{1}$$

where

B's = model parameters,

Y_i = actual tree volume (ft^3),

X_{i1} = $(dbh)^2 * height$ (in^2/ft),

X_{i2} = {1 if observation i from provenance 2, 0 otherwise},

X_{i9} = {1 if observation i from provenance 9, 0 otherwise},

and E_i = residual error;

with the reduced model not containing the interaction terms for slope:

$$\begin{aligned} Y_i = {} & B_0 + B_1X_{i1} + B_2X_{i2} + B_3X_{i3} + B_4X_{i4} + B_5X_{i5} + \\ & B_6X_{i6} + B_7X_{i7} + B_8X_{i8} + \\ & B_9X_{i9} + E_i \ , \end{aligned} \tag{2}$$

by a straight-forward F test of the reduction in error sums of squares of the complete versus the reduced model.

Similarly, overall provenance differences of regression lines were tested by comparing the above model (equation 2) with the model further reduced by eliminating the provenance variables:

$$Y_i = B_0 + B_1X_{i1} + E_i . \tag{3}$$

Subsequent analysis showed significant differences between the nine provenances for both slope and intercept (table 2). The LPL source stands out as being different from the other eight provenances (fig. 1). At larger values of height and d.b.h., LPL trees had less volume than the other provenances.

The regressions predict that an LPL tree 10 inches in d.b.h. and 70 feet tall would contain 18.1 cubic feet outside bark volume versus 19.4 cubic feet for an equivalent-size tree of the local source, about 10 percent less volume.

These differences in volume could be due to differences in height-d.b.h. relationships, tree form or taper, or a combination of these factors Therefore, further analyses were performed to determine the reason for the deviation of the LP provenance from the other provenances.

Height-D.B.H. Relationship

Linear regressions on transformed data were used to examine height-d.b.h. relationships. The models used were identical to equations 1, 2, and 3 except for substituting:

Yi = ln (height), and

Xi1 = 1/d.b.h.

The analysis showed differences among provenance in both slope and intercept (fig. 2); the most obvious difference is that in the Maryland (MD) source trees of small diameter tend to be taller than those of other sources. However, the LPL source apparently does not differ from the other sources in a way that would explain the differences in volume.

Stem Shape

The volume of a geometrical solid can be described by the equation

$$\text{Volume} = c*A*H,$$

where A is the area of the base, H is the height, and c is some constant. The constant c depends on the shape of the solid; it takes the value of 1/3 for a cone, 1/2 for a paraboloid, and 1/4 for a neiloid. (A paraboloid can be described as a cone with convex sides, and a neiloid as a cone with concave sides.) The constant c can be estimated by regression from the volume, stump diameter, and height and differences among provenances tested by using equations 2 and 3 with

Y_i = volume (ft^3),
X_{i1}= (stump area) * height (ft^3),
$B_0 = 0$, and
$B_i = c$.

The analysis indicated significant differences in stem shape among provenances. The LPL source had the lowest value for the shape coefficient, 0.319, indicating more of a tendency toward the neiloid shape (table 2). The shape coefficient for the other provenances ranged from 0.331 to 0.379, indicating a more cone- or paraboloid-shaped stem. These results indicate that the LPL source differs in shape along the central stem.

Taper

Along the central bole of a loblolly pine tree the relationship between the diameter squared and the height of the diameter measurement up the bole is approximated by a straight line (Burkhart and Walton 1985). This relationship was used in the present study to test differences in taper by using equations 1, 2, and 3 once again, substituting

Y_i = (diameter)^2 at height H up the stem, and
X_{i1} = height H,

and using the measurements along the bole of the sample trees from breast-high up to a 4-inch top diameter at 5-foot intervals.

The analysis showed a significant difference among provenances in intercept but not in slope of the fitted regressions. There does seem to be a tendency for the LPL trees to have a greater taper (table 2 and fig. 3), but the Texas (TX) source has as great a taper, yet does not deviate from the other provenances in volume as the LPL source does (fig. 1). The difference in taper is probably due to the more neiloid shape of the LPL source.

Table 2.--Fitted parameters for volume equations, and stem shape and taper of 204 sample trees of nine loblolly pine provenances

Provenance	No. sample trees	Volume equations: Intercept	Volume equations: Slope	Shape[1] (b)	Taper[2] (b)
MD	29	-0.957	0.00298	0.379	-0.829
SE NC	22	-1.137	0.00298	0.331	-0.899
E NC	22	-1.338	0.00302	0.351	-0.832
SW GA	21	-0.564	0.00290	0.335	-0.853
N AL[3]	23	-0.942	0.00300	0.350	-0.790
N AL[4]	19	-0.797	0.00294	0.344	-0.706
LPL	28	-0.133	0.00262	0.319	-0.925
E TX	23	-0.711	0.00290	0.346	-0.923
AR	26	-0.266	0.00279	0.347	-0.776

[1] Actual volume as a function of stump diameter and height: $V=b(D^2H)$. For a cone b=0.333; for a paraboloid b=0.500; for a neiloid b=0.250.
[2] Diameter squared as a function of height up the stem: $d^2=a+b(H)$ from 4.5 feet to a 4-inch top, an approximation of stem taper.
[3] Cullman County.
[4] Jefferson County.

CONCLUSIONS

The results of this study indicate that there may be important differences in volume among provenances, especially with the LPL provenance. The exact nature of the deviations is not simple, but involves differences in stem shape.

Considering the amount of LPL loblolly that has been planted across the South, serious bias may result in using locally derived volume equations in estimating volume in some areas. This work should be considered tentative, however, because it is based on only one planting. Similar analysis of other Southwide plantings is now being undertaken.

It is comforting to note, however, that despite these form differences, the LPL source ranks first in 35-year volume in this planting because of greater d.b.h., and exceeds the local source by nearly 10 percent (Schmidtling, in press.)

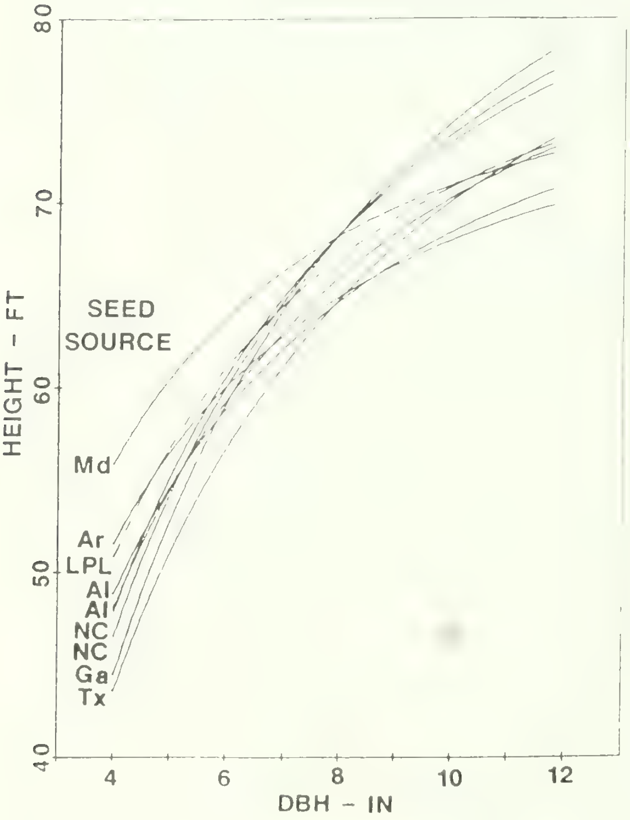

Figure 1.--Fitted volume equations for nine loblolly pine provenances planted in south Georgia after 35 years. Seed sources are identified in table 1.

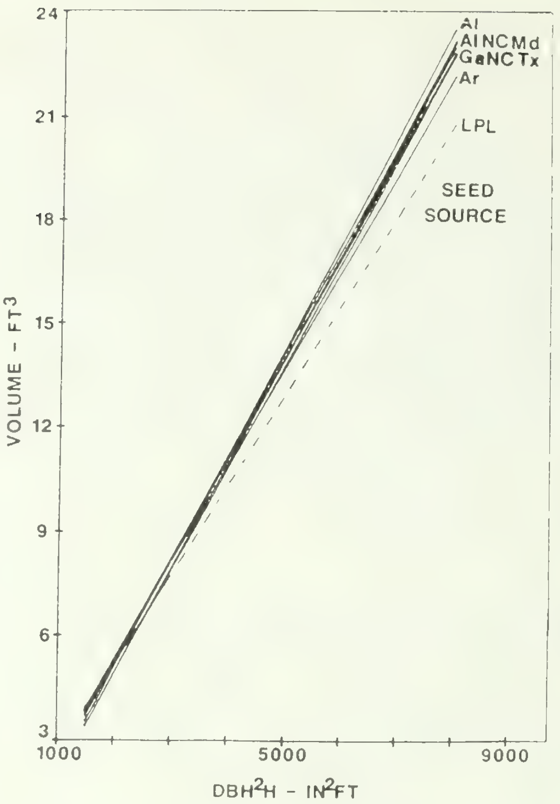

Figure 2.--Height-D.B.H. relationships for nine 35-year-old loblolly pine provenances in south Georgia. Seed sources are identified in table 1.

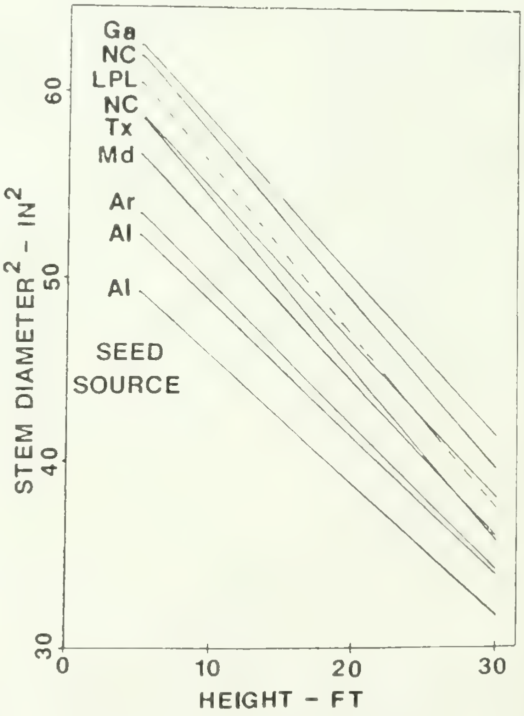

Figure 3.--Diameter-height relationship (taper index) for nine 35-year-oldloblolly pine provenances planted in south Georgia. Seed sources are identified in table 1.

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A NEW MORTALITY (OR SURVIVAL) FUNCTION FOR LONGLEAF PINE PLANTATIONS[1]

Paul A. Murphy and Robert M. Farrar, Jr.[2]

Abstract.--A mortality rate function for numbers of trees utilizing dominant stand height as an independent variable was formulated as a differential equation. Because dominant stand height also changes with age, the description of mortality must also incorporate a stand height development function. This need was fulfilled by expanding to a two-equation system by including a function for stand height development. Because the mortality rate function does not have a closed-form solution for the integral, a special fitting procedure was followed that is used in pharmacokinetic modeling. It consists of using numerical integration in conjunction with nonlinear regression. The equation and technique are illustrated using data from unthinned longleaf pine (Pinus palustris Mill.) plantations.

INTRODUCTION

One of the more striking processes in southern pine plantation development is the inexorable decline in tree numbers. Immediately after planting, establishment mortality occurs that is unrelated to competition. Quality of the planting stock, planting techniques, harshness of the planting site, weather, and a host of other factors affect seedling survival during the critical first growing season. During succeeding growing seasons but before crown closure, additional seedlings succumb to causes influenced by planting conditions or subsequent events, both largely unpredictable. Often these deaths are irregular and random and represent almost a sort of actuarial mortality. Competing vegetation can also exact a toll on the seedlings during this establishment period.

The survivors continue to grow and extend in height and crown diameter after establishment. When crown closure occurs, the trees start competing significantly with each other for light, moisture, and nutrients. As this competition intensifies, some individuals lag behind the other trees. They become retarded in height and diameter development relative to the neighboring trees. They become overtopped, and their crowns lose vigor, become sparse, and decline in size; death eventually ensues.

MODEL DEVELOPMENT

Approaches to modeling post-establishment mortality (beyond 5 years) include (1) empirically derived functions (Smalley and Bailey 1974), (2) cumulative distribution functions (Buford and Hafley 1985, Sommers and others 1980), and (3) differential equations (Clutter and Jones 1980). There are only two survival models for longleaf pine (Pinus palustris Mill.)--both are empirical. One is for unthinned plantations on unprepared cutover sites in the West Gulf region (Lohrey and Bailey 1976). The other is for naturally regenerated young stands in south Alabama (Farrar 1985).

The third approach consists of formulating a mortality rate function as a differential equation. If the mortality rate function has a closed-form solution for its integral, then the integral becomes a survival function. This approach has some advantages. It is easier to incorporate biological reasoning into the mortality rate function, and the properties of a definite integral guarantee that you need not be restricted to only one initial tree density in time, e.g. the number of trees planted. If you know the density at another age, this information can be utilized. The model is also internally consistent with regards to projection period lengths. For example, projecting from ages A_1 to A_2 to A_3 will yield the same density at Age A_3 as projecting directly from A_1 to A_3. However, some difficulty may be encountered in specifying a realistic mortality rate function that also has a closed form solution. In our following formulation, we use this approach with some modifications to specify a survival function for longleaf pine plantations.

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Initially, we wanted to specify what behaviors or relationships that the mortality rate function should have. Our first assumption was that there is always some mortality occurring that is best represented by a constant rate. This mortality is not catastrophic and is not apparently related to density and represents a constant, random (or background) mortality that continues past crown closure and the onset of competition mortality.

Secondly, competition mortality begins at about the time of crown closure and is related to stand density and site quality. Although basal area might be an adequate indicator of density at older ages, it is not for young stands. For the ages and densities encountered in our data sets, the number of trees per unit area is better. Thus, we shall adopt number of trees as our density variable.

Survival will be better initially on good sites before the onset of intertree competition. However, stands develop more rapidly on good sites; hence, competition mortality will also start earlier on these sites. Thus, we have the phenomenon of lower mortality rates initially on good sites. Later, mortality rates will be higher on good sites because of earlier, more intense competition. Therefore, the survival curves for different site indexes will intersect. Finally, as the stand ages, stand development will slow, and the mortality rates will decline. We selected dominant stand height as the variable that might be best related to these relationships. The change in dominant stand height is more rapid on good sites, and this change will decreases as the stand ages and passes the age of culmination of height growth. Dominant stand height incorporates both a measure of site quality and stand age. Therefore, we did not explicitly introduce age as a variable.

Smalley and Bailey (1974) introduced a function that exhibits better early survival at early ages and poorer survival at later ages on good sites versus poor sites. It is

$$\log(T_p/T_s) = A\{b_1 \log(T_p) + b_2 H + b_3 \sqrt{H}\},$$

where T_p is the number of trees planted per acre, T_s is the number of trees per acre surviving, A is the age from seed, H is the average total height of dominants and codominants at age A, and the b_i's are the coefficients to be estimated. However, this function was derived empirically. We want to extract the portion of this equation that has the desired theoretical property. It is the section

$$b_2 H + b_3 \sqrt{H}.$$

We write our mortality rate function as

$$\frac{dT}{dA} = \{b_1 + b_2 H + b_3 \sqrt{H}\} T \qquad (1).$$

and we can represent the natural logarithm of the projected number of trees, symbolically as,

$$\ln(T_2) = \ln(T_1) + \int_{A_1}^{A_2} \{b_1 + b_2 H + b_3 \sqrt{H}\} dA.$$

where the terms are as previously defined. The coefficient b_1 represents a background mortality rate, and the terms involving H multiplied by T describe competition mortality. The reader might infer from equation (1) and its integral that two stands with the same number of trees and dominant stand height, but different site indexes, might predict the same projected number of trees. But remember that the variable H is constantly changing during the projection period along with the number of trees. These heights are changing at different rates for different ages and sites. Therefore, although two stands might have the sam dominant stand heights and number of trees, they will have different survival patterns, given different ages and site indexes. Another feature of equation (1) is that age is implicitly introduced into the equation by dominant stand height.

In spite of its advantages, our formulation of the mortality rate function poses a difficulty. The variable dominant stand height is also changing with age or elapsed time, and its change dH/dA, must also be described by a rate equation. Moreover, if formulated this way, no closed-form solution exists for the mortality rate function. Clutter and Jones' model (1980) did not have this difficulty, because the only variables were age and number of trees. Thus, a closed form solutio exists for their rate function. The coefficients could be estimated directly by fitting our mortality rate equation by ordinary least squares However, there are two objections to this approach. First, the variables dT/dA and H must be approximated for the interval between measurement periods. We know that the ensuing rate is correct at some point during the period b the mean value theorem from calculus. But we do not know at what time it occurs. The second objection is that we are not really interested in the mortality rate function itself but rather the number of surviving trees for different projecti periods. In the fitting process, we are most interested in minimizing the variation about the function of our ultimate interest (survival) and not some associated function (mortality rate).

Dominant stand height at any age A can be described by a function that involves only stand age and site index. Therefore, we can reduce ou two-equation system to one--the mortality rate function. This reduction does not produce a function with a closed form solution. But we ca follow an approach that has been used in pharmacology called pharmacokinetic modeling. Pharmacokinetic models are usually one or more differential equations that describe the movemen of drugs in the body. The solution is to combin a nonlinear regression algorithm, preferably derivative free, with numerical integration (Ralston and others 1979). The numerical integrator provides values for each observation the regression algorithm. We selected the Runge-Kutta-Fehlberg integration routine by

Shampine and Watts (Forsythe and others 1977) and modified Leduc's (1986) nonlinear regression implementation of the simplex technique (Nelder and Mead 1965) to incorporate the numerical integrator.

Our basic procedure is to fit the integral of equation (1) by nonlinear regression. A set of trial coefficients--b_1, b_2, b_3--is determined by the nonlinear regression routine. A predicted value using these trial coefficients is then determined for each observation. Since a closed-form solution does not exist for equation (1), the predicted values must be determined by numerically integrating equation (1) by using the trial coefficients, a dominant height function to determine values of H, and the numerical integrator. The dominant height function provides intermediate values of H between the interval $[A_1, A_2]$ to the numerical integration routine as it evaluates equation (1) from A_1 to A_2. This process is repeated for each observation, and a new set of predicted values are produced. This new set and previous sets are used by the regression routine to determine a new set of coefficients. This process is done repeatedly until a set of coefficients is produced that meets the minimization criterion.

To compare the performance of this mortality model, we also fitted a modification of Smalley and Bailey's model (1974), thus

$$T_s = T_5 10^{(A-5)(a_1 \log T_5 + a_2 H + a_3 \sqrt{H})} \qquad (2)$$

where T_5 is the number of trees at age 5 years, A is the current stand age in years, H is the dominant stand height, T_s is the number of trees per acre at age A, and the a_i's are the coefficients to be estimated. The number of trees at age 5 is used in lieu of the number of trees at planting to avoid the problems of modeling establishment mortality. The 5 is subtracted from current age A so that T_s is equal to T_5 when A is 5 years. The Clutter-Jones model was also fitted because it is derived from a mortality rate function, like equation (1), and because Lemin and Burkhart (1983) found that it performed well in a comparison of four survival functions. It is

$$T_2 = \left[T_1^{c_1} + c_2 \left(A_2^{c_3} - A_1^{c_3}\right)\right]^{1/c_1} . \qquad (3)$$

where T_1 and T_2 are the number of trees per acre at ages A_1 and A_2 respectively, and the c_i's are coefficients to be estimated. In our three equations, the A_i's are ages from planting. We fitted equations (2) and (3) using derivative-free nonlinear regression (SAS Institute 1985).

DATA

To test the procedure, we used unthinned longleaf plantation data for three site conditions--old field, unprepared cutover, and prepared forest sites.

The information came principally, but not entirely, from permanent-plot records of the Southwide Pine Seed Source Study (Wells and Wakeley 1970) located on a variety of sites, primarily in the Coastal Plain, from North Carolina to Texas (see table 1 for descriptive statistics). We considered the establishment period to be the first 5 years after planting. Although planting densities varied from about 200 to 1,400 trees per acre, with the majority around 1,210 trees, the initial post-establishment (age 5) densities varied from about 100 to 1,400 trees per acre. Plots that suffered catastrophic mortality were not included. If the compounded annual mortality rate exceeded 10 percent for any 5-year growth period, the plot was excluded.

Table 1.--Summary statistics for unthinned longleaf pine plantation data sets.

Variable	Site condition		
	Old field	Cutover	Prepared
Number of plots	170	278	92
Trees per acre at age 5			
Mean	752	815	775
S.D.	295	231	303
Range	99-1209	148-1161	109-1422
Ages (years)			
Mean	10	14	12
S.D.	5	8	5
Range	5-25	5-43	5-21
Site index (ft)			
Mean	56	57	39
S.D.	8	9	12
Range	39-73	33-79	20-65

Most of the plantations were planted in the middle 1950's to the early 1960's. The old-field sites were recently abandoned agricultural fields that had very little woody competition at planting. The prepared forest sites received considerable soil disturbance due to clearing, root raking, disking, chopping, etc., to prepare them for planting. There was virtually no competition present on the prepared forest sites when planted. These were mostly on deep, sandy ("sandhill") soils that were the principal sites being intensively prepared for longleaf plantations during this period. The cutover sites had neither been cleared for agriculture nor had received any significant site preparation before planting, except for occasional burning or control of unwanted woody stems by cutting or herbicide injection. The cutover sites were essentially problem-free when planted.

Different site index functions for each site or planting condition were used to predict dominant stand height development at each age--the variable H in equation (1)--for the regression procedure.

RESULTS

The goodness-of-fit statistics for the integral of equation (1) are all quite good (table 2). Some of the variation was probably removed by considering only ages 5 and greater, which eliminates most of the establishment mortality that is notoriously hard to model. However, if one must estimate the percentage of survival from planting to age 5, we found the average survival to be 67 percent, with a standard deviation of 21 percent for all three site conditions. Neither site conditions nor site index had any appreciable effect on survival. As mentioned earlier, the planting densities were very similar for all three site conditions.

Table 2.--Goodness-of-fit statistics of survival functions for unthinned longleaf pine plantations.

Equation and site condition	Fit index[2]	Bias[3]	Absolute value[1]	
			Mean	S.D.
Equation (1)				
Old field	0.97	0.11	35.8	36.0
Cutover	0.93	3.47	46.9	44.5
Prepared	0.98	1.30	25.6	31.7
Equation (2)				
Old field	0.89	-0.81	61.9	69.1
Cutover	0.58	7.24	113.9	96.1
Prepared	0.88	-2.59	73.8	58.2
Equation (3)				
Old field	0.96	0.29	38.8	38.2
Cutover	0.93	-0.11	44.9	45.1
Prepared	0.96	-1.65	30.9	41.5

[1] Absolute value $= |y_i - \hat{y}_i|$.

[2] Bias $= \sum (y_i - \hat{y}_i)/n$.

[3] Fit index $= 1 - \sum (y_i - \hat{y}_i)^2 / \sum (y_i - \bar{y})^2$, where

y_i = observed value,

$\hat{y}_i$ = predicted value, and

y = mean value.

The goodness-of-fit statistics were lowest for the cutover sites (table 2). This data set was larger and somewhat more heterogeneous in age and site index than the other two. More variation in planting site condition occurred in this planting situation.

Figures 1-3 depict survival trends by different site indexes for the three site conditions. A separate height function and different coefficients for each condition (table 3) in equation (1) were used to generate the curves. For old fields, the survival curves exhibit better survival for good sites at early ages (fig. 1), but as age increases the heightened competition resulting from more rapid stand development exacts its toll, and the number of surviving trees is less than for lower sites at older ages. The effect of site quality on survival is even more dramatic for the prepared forest sites (fig. 2). These sites have sandy, droughty soils and are considerably poorer on the average (table 1) than the old-field and cutover sites (table 1). The harshness of these sites probably contributes to the accentuated effect of site. Moreover, being site-prepared, these planting sites were more homogeneous than the cutover sites. Site quality had little effect on survival on cutover sites (fig. 3). Possibly, the heterogeneous nature of this data set was the cause. The hardwood competition may also be more intense on these sites.

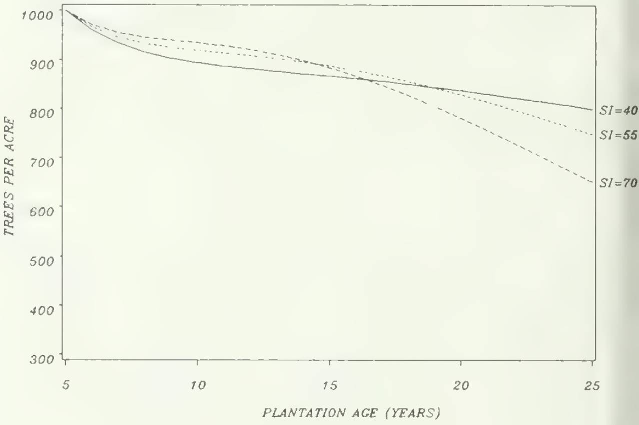

Figure 1.--Predicted survival--using integral of equation (1)--for unthinned longleaf pine plantations on old fields by site index class.

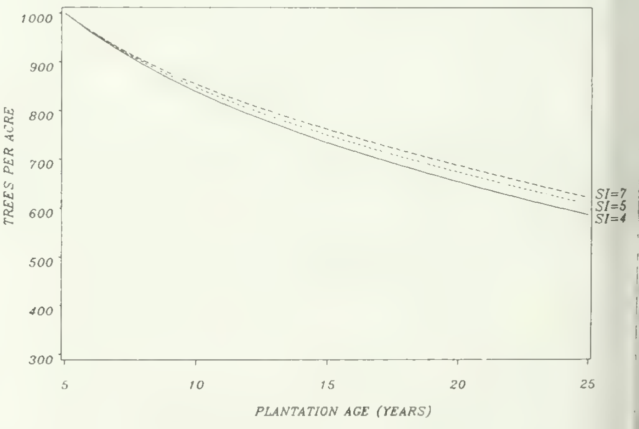

Figure 2.--Predicted survival--using integral of equation (1)--for unthinned longleaf pine plantations on cutover sites by site index class.

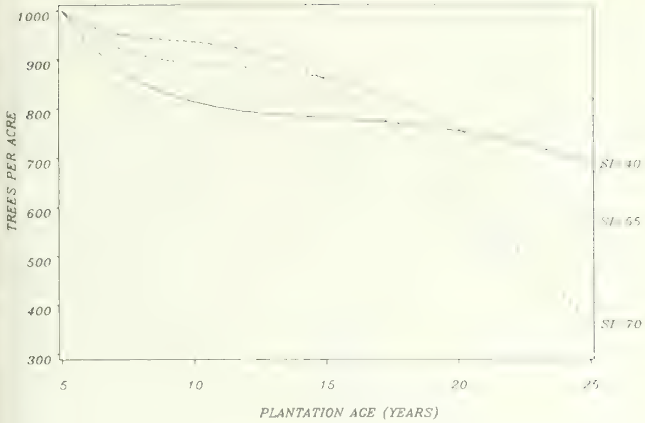

Figure 3.--Predicted survival--using integral of equation (1)--for unthinned longleaf pine plantations on prepared forest sites by site index class.

Table 3.--Coefficient estimates for equation (1) for unthinned longleaf pine plantation data sets.

Coefficient	Site condition		
	Old field	Cutover	Prepared
b_1	-0.089488	-0.049671	-0.300740
b_2	-0.003263	-0.000476	-0.011915
b_3	0.033107	0.007493	0.118840

Equation (2) did not perform as well as equations (1) or (3). Equation (3) performed better for the cutover sites than equation (1) in terms of bias and mean absolute value of the deviations. It is interesting to note that this was the condition for which the integral of equation (1) showed little site effect. On balance, there is little evidence to discriminate between equations (1) and (3) based upon the cutover results alone. However, the results from all three conditions indicate that the integral of equation (1) does slightly better than equation (3) overall.

The results for the cutover sites raised the possibility that equation (1) might be refined by the addition of more complex terms, because equation (3) contains numbers of trees and plantation age with exponents. Equation (1) might be changed to read

$$\frac{dT}{dA} = (b_1 + b_2 H + b_3 H^{b_4}) T^{b_5}.$$

This integral of this equation was fitted with all coefficients unconstrained, with the constraint that b_4=0.5, and with the constraint that b_5=1.0. None of these three variants performed any better than the unmodified form.

CONCLUSIONS

The results indicate that the integral of equation (1) adequately describes post-establishment survival in unthinned longleaf plantations. It has the capability to describe the phenomenon of better early survival on good sites versus poor sites and the reversal of this trend at later ages. This equation is also flexible so that this phenomenon is not imposed where it does not exist, as evidenced for the cutover sites. It also can be refined to include more complex terms or additional coefficients if conditions warrant.

Another avenue not explored here is to add additional equations describing various components of forest development, especially those that are derived from number of trees, such as quadratic mean diameter or basal area. The interaction of these variables can thus be modeled. This approach has been used for modeling growth in uneven-aged stands (e.g., Hyink and Moser 1983). Moreover, we ordinarily assume that height development of the dominant stand is unaffected by density. However, studies have demonstrated, depending on species and density range, that this often does exist--especially at extreme densities. Height could be added as a component, and the effect of density on its development could be described by a set of differential equations.

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LONGLEAF PINE CROWN RELATIONSHIPS: A PRELIMINARY ANALYSIS [1]

John S. Kush, Roger K. Bolton, Timothy R. Bottenfield, Ralph S. Meldahl, and Robert M. Farrar, Jr. [2]

Abstract.-- Open-grown longleaf pines were measured over a number of diameter classes to examine the relationships tree size and diameter growth rate have with crown width. These results will be used in further analyses for the development of an individual-tree growth projection system. A subset of trees from even-aged stands representing a range of ages, site qualities, and densities were sampled to provide similar data. Preliminary results show similar crown characteristics for the open-grown and even-aged longleaf pine trees when plotted against tree age, d.b.h. and 5-year radial increment growth [3].

INTRODUCTION

One of the many factors determining tree growth is the amount of space available for growth. If other factors are not limiting, a tree that has unlimited growing space should achieve its maximum crown dimensions and diameter growth. Knowing a species' estimated maximum growing space can provide a means of determining stocking levels and spatial requirements for maximizing growth. The crown dimensions and d.b.h. of open-grown trees should be related to the maximum growing space that can be utilized by a tree.

Previous studies have reported a strong relationship between crown width and d.b.h. for longleaf pine (Minor 1951), loblolly pine (Minor 1951, Strub et al. 1975), shortleaf pine (Rogers 1982), upland oaks and hickories (Krajicek et al. 1961, Minckler and Gingrich 1970), and bottomland hardwoods (Francis 1986). Several studies have reported the relationship between crown width and d.b.h. to be independent of stand age and site quality (Krajicek et al. 1961, Roberts and Ross 1965, Minckler and Gingrich 1970). Minor (1951) reported stand density had a negligible effect on the relationship between crown width and d.b.h. for loblolly and longleaf pines and Minckler and Gingrich (1970) reported the same for upland oaks and hickories.

No studies have been found which examine the relationship between periodic diameter growth rate and crown width and d.b.h. of open-grown longleaf pine (Pinus palustris Mill.). This study was conducted to examine the relationship among crown width, tree size, and diameter growth rate in open-grown longleaf pine and to compare these relationships to those found in even-aged longleaf pine stands of different age, density, and site quality levels. Future work includes the development of competition models for developing stands and an individual tree projection system for longleaf pine.

METHODS

Open-grown longleaf pine trees were sampled from south-central Alabama, southwest Georgia, and the Florida Panhandle. The sampled trees were open-grown for their entire lifetime; had no indication of disease, insect, storm damage, pruning, or other mechanical injury; were of normal form (no forks in the bole below 16 feet); and were free of excessive lean, crook, or twist. Sample tree sites included old fields, wooded pastures, road rights-of-way, fence rows, and cut-over areas where crown closure had not occurred.

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[1] Paper presented at Fifth Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Research Associates, and Assistant Professor, School of Forestry, Alabama Agricultural Experiment Station, Auburn University, AL, and Principal Mensurationist, Forestry Sciences Laboratory, Monticello, AK.

[3] The research is a cooperative effort between the U.S. Forest Service (Region 8 and Southern Forest Experiment Station) and Auburn University.

An effort is being made to sample 3 trees per one-inch d.b.h. class from 1 to 24 inches. Thus far, 74 open-grown longleaf pines have been measured. If a tree meets the open-grown criteria, the crown diameter is measured in two directions, one along the crown's longest horizontal axis and one at right angles to this longest axis (as estimated by their vertical projection to the ground). Magnetic azimuth of the longest horizontal crown axis is also measured. Diameter at breast height is recorded. Heights to the point of greatest crown width and base of the live crown, and total height are measured. Bark thickness and tree age measurements are taken parallel to the tree's greatest horizontal crown axis and perpendicular to it. From the increment cores, 5-year radial growth increments are measured from the cambium to the pith.

To provide a comparison, 57 trees have been sampled from the isolation strips on existing even-aged plots within the regional longleaf pine growth study (Farrar 1978, 1979, 1985) on the Escambia Experimental Forest in Brewton, AL. The study consists of 200+ permanent 1/10- and 1/5-acre net measurement plots located throughout much of the Southeast. A 1/2-chain isolation strip is maintained around each plot by thinning to the same residual basal area level as the net plot. From these isolation strips, three dominant and co-dominant trees were sampled across different age, basal area, and site index classes. Kush et al. (1987) provide a further description of this study.

RESULTS AND DISCUSSION

Initial analyses have compared tree age, periodic radial growth for the last 5 years, and d.b.h. to crown width, and crown ratio. Table 1 presents the averages of these variables for the open-grown and even-aged data.

Table 1.--Variable means for open-grown and even-aged longleaf pine trees measured.

Variable	open-grown (n = 74)	even-aged (n = 57)
d.b.h. (inches)	8.2	13.0
age (years)	15	51
crown width (feet)	17.9	29.8
crown ratio	0.73	0.44
5-year radial growth (inches)	1.04	0.42

There are differences between the means of the two data sets, especially in age and d.b.h. In part, some of the difference is due to the trees available to measure on the Escambia Experimental Forest. The smallest even-aged trees measured were 5 inches d.b.h. and 20 years old (at d.b.h.). Concerning open-grown trees, some were measured as small as one inch d.b.h. and one-year old at d.b.h. Another possible reason for the difference is the even-aged data set only utilized co-dominant and dominant trees. The means will change when information from suppressed and intermediate trees are analyzed.

Preliminary analyses have been mainly limited to examining the relationships tree age, d.b.h., and 5-year radial growth have with crown width. Tree age, d.b.h., and 5-year radial growth are plotted against crown width (Figs. 1, 2, and 3) for the open-grown and even-aged trees.

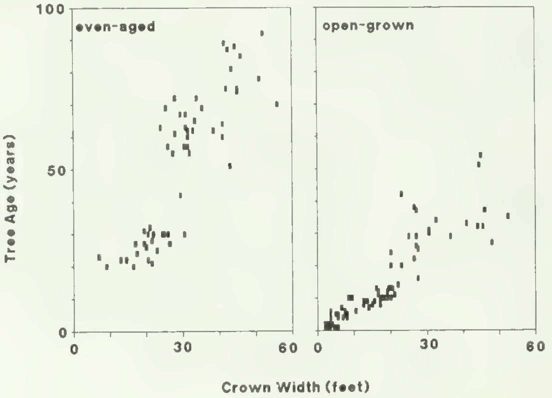

Figure 1.--Tree age vs. crown width.

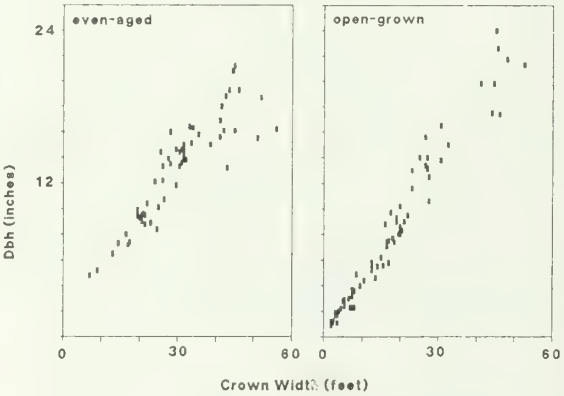

Figure 2.--D.b.h. vs. crown width.

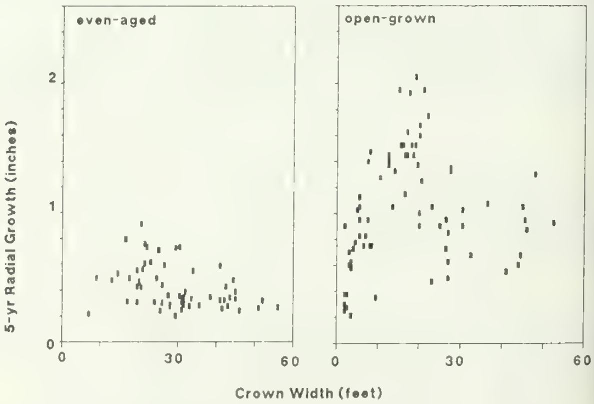

Figure 3.--Five-year radial growth vs. crown width.

A very strong relationship exists between d.b.h. and crown width for both the open-grown and even-aged trees (fig. 1). The trend for open-grown trees remains fairly linear as d.b.h. increases, but begins to spread out for the even-aged trees with increasing d.b.h. This may be due to stand density effects but this has not been examined.

A relatively strong relationship exists between tree age and crown width for the open-grown and even-aged trees (fig. 2). These two findings support earlier research by Vezina (1964) working with balsam fir, black spruce, and white birch in Canada; Francis (1986) with bottomland hardwoods in Mississippi; and Sprinz and Burkhart (1987) with loblolly pine in the Southeast.

There is no obvious relationship between 5-year radial growth and crown width (fig. 3). Even-aged trees show no trend between the two variables. The plot for open-grown trees increases rapidly to a point but then turns downward. This may be more related to age as radial growth will decrease with age while crown width will increase.

Tree age, d.b.h., and 5-year radial growth were plotted against crown ratio also. Though crown width performs better than crown ratio when compared to d.b.h. and age, both variables display weak relationships with 5-year radial increment growth. Guttenberg (1953) found similar results for loblolly pine in Arkansas, but indicated that crown ratio was a better indicator of tree vigor than crown width.

CONCLUSION

Initial analyses comparing crown width with d.b.h., age, and 5-year radial growth have generally supported the findings of similar research conducted on a variety of species. In addition to the work examining the relationship between crown width and tree size of open-grown longleaf pine, plans for future work include:

1. Investigating crown competition using a multi-dimensional approach (e.g. crown projection area, crown volume).
2. Investigating the influence of crown competition on intermediate and suppressed trees in even-aged stands.
3. Investigating crown relationships of individual trees at varying stand density levels.
4. Utilizing long term inventory data from the regional longleaf pine growth study for modeling tree and crown relationships of individual longleaf pine trees.

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PREDICTION OF TOTAL STAND INGROWTH IN SOUTHEASTERN MIXED SPECIES BOTTOMLAND HARDWOODS[1]

Christopher B. Davidson, William L. Hafley,
Douglas J. Frederick and Dennis L. Mengel.[2]

Abstract-- The North Carolina State University Hardwood Research Cooperative has recently developed a growth model 'BYPS' for natural bottomland hardwood stands in the Southeast. Ingrowth is a necessary component of growth models if stand dynamics are to be realistically simulated. The objective of this study was to develop an equation for the prediction of total stand ingrowth to be included as a sub-model within BYPS. Total stand ingrowth refers to those trees that are below 14.2 centimeters in diameter breast height at the beginning of the inventory period, but are greater than 14.2 centimeters at the end of the period. Length of the inventory period is five years. The primary assumption used is that the rate of total stand ingrowth is a function of stand density and can be quantified using basal area per hectare and number of trees per hectare. Permanent growth and yield plots were used to fit a nonlinear model of the form $I = a\, e^{-d\,(G/N)}$.

INTRODUCTION

Mixed hardwood stands of natural origin com-ise approximately 60 percent of the total orestland of the southern United States night,1981). Recently, there has been increas-ng interest in their development and methods to ffectively manage them for the production of ommercially desirable species and products. Ef-ective forest management depends in large part the ability to accurately predict future tand growth and yield. Models used in forest owth prediction are typically composed of equa-ons that describe the growth components survivor growth, mortality, cut and ingrowth) ndividually and then, in combination, provide a sis for prediction of total stand growth.

The North Carolina State University Hardwood Research Cooperative has recently developed a growth model (The Bottomland Hardwood Yield Projection System - BYPS) for natural bottomland hardwood stands in the Southeast. The BYPS model is an interactive computer program that calculates the current stand cruise statistics, projects the current stand five years into the future, and calculates new statistics for the projected stand. In addition to total stand projections, projections can be made for individual species or species groups. The user may also define the merchant ability standards and economic criteria to be used in the projections. The current stands diameter distribution is projected using a diameter-class matrix model. Mortality is a probability function, and sub-merchantable ingrowth (ingrowth into the sub-merchantable diameter classes) is the mean number of ingrowth trees per diameter class calculated from the sample data. The objective of this study was to develop an equation for the prediction of total stand ingrowth to be included as a sub-model within BYPS. Total stand ingrowth refers to those trees that are below 14.2 centimetres in diameter breast height at the beginning of the inventory period, but are greater than or equal to 14.2 cm in diameter at the end of the period. The length of the inventory period is five years.

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DATA

The data used in the study consisted of fifty six permanent growth and yield plots established throughout the southeastern United States. States represented were Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas and Arkansas. Each plot is 0.08 hectare in size with a 0.04 hectare sub-plot. Merchantable trees (those greater than 14.0 cm dbh) are measured on the 0.08 hectare plot; submerchantable trees (4.1 to 14.0 cm dbh) are measured on the 0.04 hectare plot. Each tree is individually numbered to facilitate remeasurement and the tree number reflects the current status of the tree; that is, whether it is merchantable, submerchantable, ingrowth or mortality. Six bottomland site types are represented; muck swamp, peat swamp, wet flat, red river bottom, black river bottom and branch bottom.

METHODS

A literature review suggested use of a negative exponential equation for the prediction of total stand ingrowth. In 1967, John W. Moser formulated a model for use in total stand ingrowth prediction based on the assumption that the ratio of basal area to number of trees per acre is an accurate indicator of the rate of total stand ingrowth. This ratio represents the arithmetic mean basal area per tree within the stand. The diameter corresponding to the arithmetic mean tree basal area is the quadratic mean tree diameter and thus the ratio is an estimate of the quadratic mean diameter (Husch et.al.,1982). The basis for this assumption is a trend that has been observed and documented in previous research (Ek,1974; Shifley et.al,1982; Michie and Buongiorno,1984). As the quadratic mean diameter of a stand of trees increases, the rate of total stand ingrowth decreases, eventually to the point of zero ingrowth. Thus, stands with a large number of trees and a small mean diameter are expected to have higher rates of ingrowth than stands composed of smaller numbers of trees and a larger mean diameter.

Ek (1974), using Moser's equation as a base for his investigation, formulated a negative exponential equation that included the number of trees per acre as a predictor variable. Based on the work of Moser (1967) and Ek (1974), three equations were proposed for predicting total stand ingrowth.

1) $I = a\, e^{-d\,(G/N)}$

2) $I = a\, N^{b}\, e^{-d\,(G/N)}$

3) $I = a\, N^{b}\, G^{c}\, e^{-d\,(G/N)}$

where:
I = ingrowth trees per hectare over a five year period
G = initial stand basal are per hectare
N = initial number of trees per hectare
e = base of natural logarithms

The first equation is Moser's reproduced in it's entirety. The second and the third are variations of Moser's and Ek's original equations. Each equation is intrinsically linear; linear equations were achieved by transformations using natural logarithms. Estimates of the parameters were obtained by ordinary least squares regression analysis using PROC REG in SAS (SAS Institute, 1985). These estimates were then used as the starting values for a non-linear regression analysis using PROC NLIN in SAS (SAS Institute, 1985). Several methods are available within PROC NLIN for solving the normal equations. The method that was used is the iterative derivative free, DUD option. Estimates of the parameters within each equation were obtained and plots of the residuals were made. Each equation was also examined using plots of ingrowth versus the independent variables showing actual and predicted values.

RESULTS AND DISCUSSION

Based on nonlinear regression statistics of each equation, the residual plots, and plots of actual versus predicted values, equations 2 and 3 were rejected as being unacceptable for the prediction of total stand ingrowth. Equation 2 exhibited a number of features that made it undesirable for use. The most significant of these was a positive sign on the third parameter estimate 'd'. This is not the expected or the desired sign since it is known that ingrowth decreases with increasing stand diameter. Also, of the three parameter estimates two had confidence intervals that bracketed zero. This indicates that these estimates may have a value of zero and thus the independent variables may not be significant in the prediction equation.

Equation 3 was a better predictor, however, it's nonlinear regression statistics indicated some problems. All four parameter estimates had confidence intervals that bracketed zero. In addition, there were indications of high correlations between three of the parameters. These problems did not appear to have any delitirious effects in the initial stages of equation fitting, but when final parameter estimates were obtained the equation proved to be unstable.

The final equation chosen for use in the prediction of total stand ingrowth in the BYPS growth model was Equation 1. It is presented below with the final parameter estimates.

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PROGRESS ON SHORTLEAF PLANTATION, DATA POOL AND GROWTH PREDICTIONS[1]

T. Dell, J. Koretz and E. Shoulders[2]

Abstract.--Interest in growth and yield models for shortleaf pine (Pinus echinata Mill.) plantations persists due to: (1) a National Forest emphasis, (2) questions related to air pollution influences, and (3) the need to compare shortleaf to loblolly pine (P. taeda L.) in order to determine which species is more suitable for a specific location. A data pool that covers the natural range of shortleaf pine has been assembled and work has begun to develop a size class prediction system for plantations of the species under a variety of situations. A review of the only system previously available led to provisions for avoiding misunderstandings regarding the use of age from seed rather than plantation age.

INTRODUCTION

Forest managers have generally sought to eliminate the shortleaf pine (Pinus echinata Mill.) component in naturally regenerated stands and have persistently planted loblolly pine (P. taeda L.), even in areas where shortleaf was the only naturally occurring pine. Nevertheless, the fact that shortleaf pine is second in importance only to loblolly in the existing forests of the South was emphasized in the papers of the Symposium on the Shortleaf Pine Ecosystem (Murphy 1986). Summaries of the results from growth and yield studies in the same proceedings testify that the species has however, received the least attention of the four major southern pines. For plantations, there is only one system that offers predictions by size classes (Smalley and Bailey 1974), and it was based on data from unthinned stands on old-fields in a limited portion of the southern highlands. Another study, by Williston and Dell (1974), provided equations for stand-based estimates of basal area and volume growth trends of north Mississippi plantations.

Recent growth and yield studies have also ignored shortleaf, and cooperative efforts have centered strictly on loblolly plantations. Remeasurements of some long-term studies on shortleaf plantings did continue, but priority was given to other species in the allocation of resources to accomplish data pooling and to develop prediction systems. At the present, less than 25,000 acres of new shortleaf plantations are established annually. It is the existing volume in naturally regenerated stands, not the plantations, that qualify shortleaf as the second most important tree species in the South. However, questions related to a National Forest emphasis, air pollution, and site suitability encouraged us to study available equations and initiate work on a new system utilizing data now on hand for shortleaf plantation.

Contrary to the general reforestation procedures, National Forest managers in the South reforest with shortleaf and view it as the preferred management type on over 2.8 million acres of National Forests in 14 states from Virginia to Texas. Kitchens (1986) explains that, with quality sawtimber and long rotation objectives, interpretation of existing yield data by the Forest Service shows no advantage in using loblolly. Also, in plantings north of the natural range of loblolly, shortleaf has had a lower risk of catastrophic loss during a long rotation. Catastrophic loss implies wide spread mortality across the full range of size classes, rather than the suppression mortality of mainly smaller trees. Catastrophic losses are usually associated with major destructive agents such as insects, disease, or frost damage. Growing shortleaf is an obvious way for the Forest

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Service to comply with the mandate for diversity in the National Forests, and the shortleaf tree improvement work should provide faster growth as well as better quality.

The range maps of the southern pines (Koch 1972) and the maps of anticipated areas of higher atmospheric pollution (Bormann 1985) make it clear why shortleaf is being considered as well as loblolly in the evaluation of pollution impacts. Shortleaf is the prevalent species in the expected high pollution zone extending along the northern and western limits of the southern pine region. At research centers in Texas and North Carolina, shortleaf trees are being grown in controlled-environment chambers with metered amounts of air pollution. The extrapolation or interpretation of such studies to forest conditions will require model developments that can in part be based on the plantation data and growth prediction equations. Direct tests of hypotheses regarding changes in growth rates, given adjustments for stand and weather variables, are also needed in preliminary considerations of pollution influences and can be done with the plantation data base. Growth data from research on naturally regenerated shortleaf is very limited, and the inventory data are not well suited to model-based adjustments for evaluations of growth trends (Dell 1987). Thus, the available long-term studies in shortleaf plantations provide the only comprehensive collection of growth data available for the species.

Interest in both planting loblolly further to the north and west and establishing shortleaf well beyond the northern limits of its natural range (Rink and Wells 1988) provides a demand for more growth and yield prediction capability. Studies, such as the one reported by Woods and others. (1988) state the current questions and demonstrate how growth information can be utilized.

DATA ON HAND

We pooled the data from five shortleaf pine plantation research projects (table 1). Where necessary, the information was coded into machine readable form and edited by elaborate computer based procedures. It is in many ways a surprisingly rich collection, with a very wide diversity in geographic locations and site conditions. The data's principle liability is a definite confounding in time. Plots were planted about 30 years ago, and measurements have been taken up until the present, but few new plots have been installed. Another disappointing aspect of the data pool concerns thinning treatments. Thinning is inherently a part of the long rotation, quality sawtimber scenario associated with shortleaf. Smalley (1986) summarized related information and stated the need for thinned stand quantification. However, the accumulated data pool for shortleaf contains limited information on thinning trials when compared to other southern pines (Dell 1983). Murphy (1986), in a summary of growth and yield information for shortleaf, provided details from previous studies including those in southern Illinois and exposed the lack of thinned plantation results. We will be required to extrapolate from the limited data, and may have to take some guidance and data from thinned, naturally regenerated, even-aged shortleaf studies for future modeling efforts.

Table 1.--Sources of shortleaf plantation data.

Data set		Number of observations
Shortleaf seed source	(SS)	5,880
Choice-of-species	(CS)	430
Forest industry	(FI)	100
Williston fixed-area plots	(WF)	185
Smalley interior highlands	(IH)	104

The most demanding aspect of our work thus far has been the editing of the shortleaf seed source (SS) data. The 30-year measurements for this study are on hand, but the data were analyzed (Wells and Wakeley 1970) only through the first 10 years. An overview of the study objectives and field installation was given in Wells and Wakeley's reporting of the interim results. A total of 23 shortleaf geographic seed sources were included, and there is at least 1 installation in the vicinity of each seed source. In all 40 installations were successfully established over 2 phases. The first phase in the 1952-53 planting season was plagued by drought, and many installations failed, but the second in the 1956-57 season was more successful. A selected subset of the sources is termed a series in this study, and six series were defined to test specific hypotheses. An installation consisted of a randomized block experiment with four blocks, each having one plot of each of the seed sources included in the particular series. Two of the series involved seven sources and four involved six sources. Each plot contained 121 trees (11 rows by 11 columns) of a given seed source planted on a 6- by 6-foot spacing, with the central 49 trees used for measurement. Measurements were taken at ages 1, 3, 5, 10, 15, 20, 25, and 30 where possible, but some plots have been destroyed or measurements were not taken for various reasons. If a "plot observation" is defined as the collecting of data on one plot at one point in time, then there are 5,880 plot observation available in the SS data set (table 1). At young ages these measurements involved only height determinations, but diameter measurements were included later.

The original objectives of this genetics investigation can now be approached with the edited data and we can use some, or perhaps all, of the data in the growth and yield work. About one-fifth of the plots can be viewed as local sources, and we are deliberating on using just them in our modeling. Obviously, if a system can be devised that works adequately across all the sources it would be of greater potential value in making predictions for the current situation where essentially all planting is done with seed from tree improvement programs.

The second largest data set (table 1) was extracted from the shortleaf data from the choice-of-species (CS) investigation that has been conducted by the USDA Forest Service, Silviculture Research Unit at Alexandria, LA, over the past 30 years. A good overview of this CS study and the related publications of interim results is given by Shoulders (1983) and covers the period through age 20. The general objective of this research was to compare the performance of the four major southern pines (loblolly; shortleaf; slash, *P. elliotti* var. *elliotti* Englm.; and longleaf, *P. palustris* Mill.) on a variety of sites. The study area covers examples of most of the pine growing sites in Louisiana and southern Mississippi. Plantations were established at 113 locations, but shortleaf was judged inappropriate for many of the locations, and the other three species were the only ones planted. Initially there were three replications for each species being tested at each location. For shortleaf we have records on 86 plots covering 34 locations, and each of the plots has been remeasured 5 times, including the observation made at plantation age 25. The plots of this study have never been thinned.

Of the three remaining data sets, the forest industry (FI) and Williston fixed-area plots (WF) involve repeated measurements. The FI data are from Georgia and have not been described in the literature. Background on WF plots is given by Williston (1978). The IH plots were measured just once, and the data set is covered fully by Smalley and Bailey (1974).

BACKGROUND DEVELOPMENTS

In dealing with the SS data, the trees were not classified by crown classes, and thus the average height of dominant and codominant trees (H_{DC}) cannot be computed directly. Tree heights were taken on each plot, and we have sought a way of estimating H_{DC} for the SS plots by constructing a prediction equation using the IH and CS data sets. One equation developed thus far is:

$$H_{DC} = H_{ALL}\,[1.0 + \exp\,(0.2639 - 0.03999\,H_{ALL} - 21.71/Ap - 79.77/T_S)],$$

where H_{ALL} = average height for all trees,
Ap = plantation age (number of growing seasons since field planting), and
T_S = number of trees per acre surviving at the given Ap.

This was fitted with the combined data from the IH and CS studies and works about equally well in each of them. The simple correlation of predicted and observed H_{DC} values is +0.985, and the average deviation (prediction-observed) is -0.64 feet; thus there is a tendency to predict a bit too low. Applications of this general model for a variety of situations are being summarized by Farrar and Dell[3].

It has become customary for plantation growth and yield systems to express age in terms of Ap as defined above and to use a base age (B) of 25 years for site index specification. We will follow these conventions in our developments; thus B will equal an Ap of 25. However, Smalley and Bower (1971) utilized age from seed (A_S) in their site index equations with a base age of 25 years from seed and an assumption that 1-year-old bare-rooted nursery stock was planted. Smalley and Bailey (1974) followed through with these A_S arguments in developing their yield system. These authors fully explain their formulations and accomplish error free applications of the equations in their figures and tables, but problems crop up because of the almost complete orientation of current users to the Ap mind set. Users of the equations sometimes simply ignore the distinction between A_S and Ap. Thus, they introduce various errors or have difficulties in interpreting the predictions.

The matter is readily resolved by adopting the Ap convention, remembering that A_S = Ap + 1, and reformulating the A_S equations. Specifically, the Smalley and Bower (1971) shortleaf site index must be written with a base age of 25 growing seasons since outplanting (26 years from seed) and an age term of Ap + 1. The equation is then:

$$\mathrm{LOG}_{10}(H_{DC}) = \mathrm{LOG}_{10}(SI) + 2.896448\ [(1/\mathrm{SQRT}(26)) - (1/\mathrm{SQRT}(Ap+1))].$$

The graph of this equation is shown in figure 1, with the horizontal scale expressed in years since outplanting and height on the vertical scale. This portrays the height-over-age relationship defined by Smalley and Bailey, but allows the user to specify the plantation age and a 25-year plantation age base for the site index. Note that the height at an Ap of 49 years corresponds to the height at 50 years from seed and provides the site index if the base age is changed to the reference point commonly used in naturally regenerated stands. Thus the 50-foot site index curve for a 25-year plantation age base would be designated as the 72-foot site if 50 years from seed were used as the base age. It should be clear that the essentially arbitrary redesignation of a the base age does not change the reality of the data used to fit the height-over-age relationship. In this case, data are from old field plantations that were at most 30 years old and clearly do not accurately define the height-over-age curve that would be expected with, say, naturally regenerated stands through an age of 70 years.

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[3] R. M. Farrar Jr. and T. R. Dell. Estimating dominant-stand height without crown classification in unthinned southern pine plantations [in preparation].

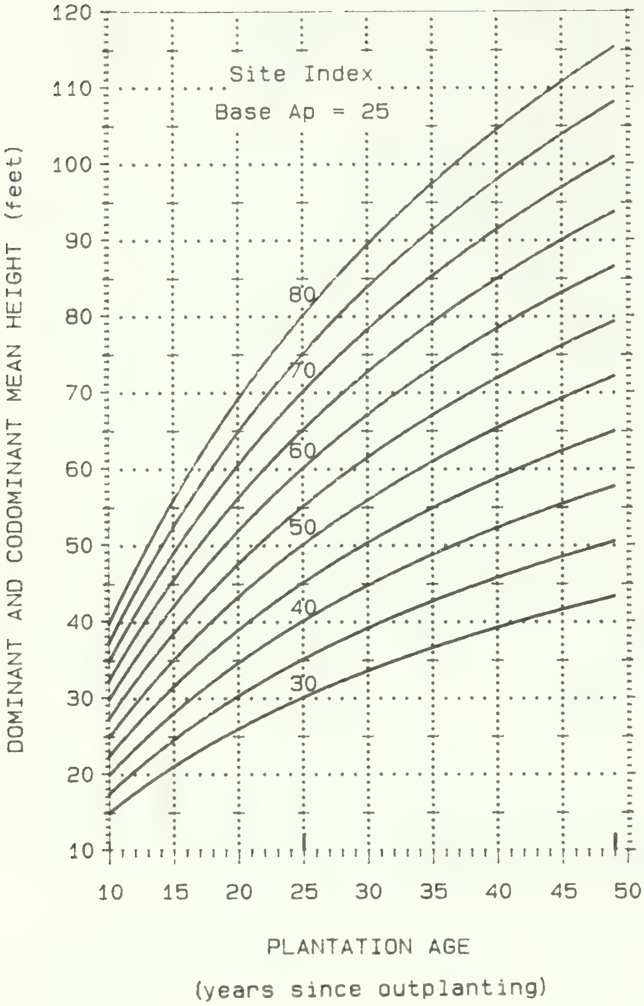

Figure 1.--Site index curves for shortleaf pine plantations using the Smalley and Bower (1971) coefficient but with A_p on the horizontal axis and a base age of A_p = 25 years.

Using the growth and yield prediction system provided by Smalley and Bailey (1974), with the current A_p conventions, involves specifying the base age as 26 years rather than the 25-year value used to generate the tables for the 1974 publication. The computer program related to their publication wisely accommodates such changes and requires a base age designation. One must also remember that the program is working with the $A_S = A_p+1$ definition of age; thus if you want to predict the yield after 10 growing seasons in the field you must specify 11 as the age argument for the program. It might seem that these differences in just 1 year would not make much difference and that we are engaged in a hair splitting exercise here, but table 2 shows otherwise.

In the following example we assume the intent is to get yield estimates for a plantation age of 10 with 400 surviving trees per acre and a site index of 60 feet (base age of A_p = 25). However, various types of errors are made in conveying the arguments to the program. The case when the obvious errors for age and index age are committed is A_eB_e. In the other two cases of errors, only one incorrect specification is involved.

Clearly there is a very different effect when each of the arguments is incorrectly specified, and a compensating effect occurs when both errors A_e and B_e are made. The differences in yield estimates are large relative to the correct value and cannot be ignored.

ADDITIONAL DATA

One of our purposes in providing this progress report is to emphasize that additional data would be very welcome. It is not likely that major new field studies will be initiated or that other comprehensive modeling efforts will be undertaken in the foreseeable future. If additional plot information from either temporary or remeasured

Table 2.--Yield estimates with the correct arguments and with three types of errors for a hypothetical stand

Error type	Input arguments				Output volume estimate ib 4-in ob top
	Base Age	SI	A_S	T_S	
	years	feet	years	no./acres	ft^3/acres
NONE	26	60	11	400	650
A_eB_e	25	60	10	400	536
AB_e	25	60	11	400	710
A_eB	26	60	10	400	487

fixed-area plots exists, now is the ideal time to incorporate such data into the various files before coefficients for system components are fitted. In particular, we would like to be able to expand the available data on thinning trials to represent a sufficient variety of density regimes and geographic locations.

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EVALUATING INDIRECT AND DIRECT METHODS OF CONSTRUCTING LOCAL VOLUME EQUATIONS [1]

Quang V. Cao [2]

Abstract.--In some cases in timber cruising, all tree diameters are measured but only a few tree heights are determined. A local volume equation is needed to yield bole volumes from diameters at breast height. Two methods to develop a local volume equation are discussed. The indirect method involved first establishing a height-diameter relationship from the subset of data in which heights were measured, and then substituting dbh's and predicted heights into a standard volume equation. In the direct method, tree volumes were computed for the subset having both dbh's and heights. A regression equation was then developed to predict volumes directly from diameters. The indirect method with equation ln(H) = a + b/D performed most consistently to predict volumes in terms of bias, absolute bias and percent explained variation.

INTRODUCTION

Individual tree volumes can be predicted from standard or local volume equations. Data requirements for standard volume equations are diameter at breast height (dbh) and either total or merchantable height. Local volume equations, which require dbh only, often receive preference by foresters because tree height measurements are time-consuming. Inventory data may consist of diameter measurements of all trees and height measurements of only a small subset of these trees. Therefore the objective is to estimate bole volumes of all measured trees given this kind of data. Local volume tables can be constructed either directly by predicting volume from diameter (direct method) or indirectly by first predicting height from diameter and then substituting dbh and predicted height into an existing standard volume equation (indirect method). In this study, predicted volumes obtained from these two methods were evaluated.

DATA

Data from a loblolly pine mutual competition study at the Hill Farm Research Station, Homer, Lousiana, were used in this study. Diameter outside bark and bark thickness at 25-inch intervals starting from the stump to the tree top were measured on 291 trees felled during a thinning at age 21. Total height and dbh were also recorded for each tree. Sprinz et al. (1979) described this data set in detail. Cubic-foot volume inside bark of each 25-inch section was computed using the conic formula; the top section was treated as a cone. Total tree volume was obtained by summing section volumes. Table 1 provides a description of the data set.

Table 1.--Description of 291 felled loblolly pine trees at Homer, Louisiana

Variable	Minimum	Mean	Maximum
DBH (in)	4.5	9.1	19.0
Total height (ft)	24.6	56.9	76.8
Total volume (ft^3)	1.7	9.9	44.3

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STANDARD VOLUME EQUATIONS

Two commonly-used standard volume equation forms were used in this study. Equations with parameters estimated from the data set (291 trees) are as follows:

$$V = 0.46718 + 0.00178\ D^2H \qquad (1)$$

$$\ln(V) = -5.77175 + 1.97659\ \ln(D) + 0.88731\ \ln(H) \qquad (2)$$

where V = total cubic-foot volume inside bark,
D = diameter at breast height in inches, and
H = total height in feet.

The equations account for 96.69% and 95.65% of the variation, respectively. Equation (1) is the well-known combined variable volume equation, whereas equation (2) is Schumacher's logarithmic equation.

INDIRECT AND DIRECT METHODS

The indirect method to construct a local volume equation involved two steps. First, a height-diameter relationship was established from the subset of data in which heights were measured. Second, dbh's and predicted heights (from the height-diameter equation above) were substituted into a standard volume equation, resulting in a volume equation that required only dbh as the independent variable. Thus for a given standard volume equation, each height-diameter relationship implied a corresponding local volume equation. The implied local volume equation was obtained by substituting the height-diameter equation into the standard volume equation. Three height-diameter models were examined in this method; each resulted in a different implied local volume equation. Table 2 shows various forms of these local volume equations.

In the direct method, tree volumes were computed for the subset with both diameter and height measurements using an existing standard volume equation. A regression equation was developed to predict volumes directly from diameters for this subset. This local volume equation was then used to compute volumes of all trees in the data set. Height can be expressed as a function of dbh by equating the local and standard volume equations. This means the new local volume equation assumed a certain relationship between height and diameter. The three local volume equations considered in this method and their implied height-diameter relationships are shown in Table 3.

For the logarithmic standard volume equation, the height-diameter equation

$$\ln(H) = c_0 + c_1\ \ln(D)$$

from the indirect method produced identical results to the direct method that employed the following local volume equation:

$$\ln(V) = b_0 + b_1\ \ln(D).$$

It can be shown that these two particular methods are indeed equivalent.

EVALUATION OF DIRECT AND INDIRECT METHODS

The approaches were evaluated based on the following criteria:

(1) Bias: average of the differences in percent between observed and predicted volumes.

$$\text{Bias} = (100/n) \sum_{i=1}^{n} (V_i - \hat{V}_i)/V_i$$

where n = 291 trees,
V_i = observed total volume inside bark in cubic feet for the ith tree,
$\hat{V}_i$ = predicted total volume inside bark in cubic feet for the ith tree.

(2) Absolute bias: average of the absolute differences in percent between observed and predicted volumes.

$$\text{Absolute Bias} = (100/n) \sum_{i=1}^{n} |V_i - \hat{V}_i|/V_i$$

(2) Fit index: which is computationally similar to R^2.

$$\text{Fit index} = 100\ [1 - \sum_{i=1}^{n} (V_i - \hat{V}_i)^2 / \sum_{i=1}^{n} (V_i - \bar{V})^2]$$

Let us assume that tree heights were measured on only 5% of all trees, or 14 trees, and all 291 tree diameters were taken. To simulate this situation, 14 trees were randomly selected from the data to form the subset (an alternative sampling method by a random selection of the trees from each diameter class yielded similar results). Various methods mentioned above to compute tree volumes were carried out and the three evaluation statistics were computed for each method. This procedure was replicated 30 times.

Different proportions of the data containing height measurements were considered. These sample sizes were 5, 10, 20, 30, 40, and 50 percent. Each proportion was replicated 30 times.

RESULTS AND CONCLUSION

Table 4 shows values of the three evaluation statistics (average of 30 replications) and their rankings for the different methods in the case of the combined variable volume equation. A similar table (Table 5) is presented for the logarithmic volume equation. As expected, the precision of the methods based on the absolute bias and fit index generally increased as sample size increased. The values of the three evaluation statistics were close for all methods considered ere. The overall rankings of each method for arious sampling sizes are shown in Table 6. he log (height) - inverse diameter equation of he indirect method produced more consistent esults than other approaches. This popular eight-diameter equation worked relatively well or both types of standard volume equations and or different porportions of trees whose heights ere measured. Based on the results from this tudy, we can expect the same approach to erform satisfactorily for other types of tandard volume equations or tables.

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able 2.--Height-diameter relationships and their implied local volume equations

tandard Volume Equation	Height-Diameter Relationship	Implied Local Volume Equation
$= a + b D^2H$	$\ln(H) = c_0 + c_1/D$	$V = a + b D^2\exp(c_0 + c_1/D)$
	$\ln(H) = c_0 + c_1\ln(D)$	$V = b_0 + b_1 D^{b_2}$
	$H = c_0 + c_1\ln(D)$	$V = b_0 + b_1D^2 + b_2D^2\ln(D)$
$n(V) = a + b \ln(D) + c \ln(H)$	$\ln(H) = c_0 + c_1/D$	$\ln(V) = b_0 + b_1 \ln(D) + b_2/D$
	$\ln(H) = c_0 + c_1\ln(D)$	$\ln(V) = b_0 + b_1\ln(D)$
	$H = c_0 + c_1\ln(D)$	$\ln(V) = a + b \ln(D) + c \ln[c_0 + c_1\ln(D)]$

able 3.--Local volume equations and their implied height-diameter relationships

tandard Volume Equation	Local Volume Equation	Implied Height-Diameter Relationship
$= a + b D^2H$	$V = b_0 + b_1 D + b_2 D^2$	$H = c_0 + c_1/D + c_2/D^2$
	$V = b_0 + b_1 D^2$	$H = c_0 + c_1/D^2$
	$\ln(V) = b_0 + b_1\ln(D)$	$H = c_1/D^2 + c_2D^{b_1-2}$
$n(V) = a + b \ln(D) + c \ln(H)$	$V = b_0 + b_1 D + b_2 D^2$	$H = [c_1D^{-b} + c_2D^{1-b} + c_3D^{2-b}]^{1/c}$
	$V = b_0 + b_1 D^2$	$H = [c_1D^{-b} + c_2D^{2-b}]^{1/c}$
	$\ln(V) = b_0 + b_1\ln(D)$	$\ln(H) = c_0 + c_1\ln(D)$

Table 4.--Evaluation statistics for different methods when the standard volume equation is the combined variable equation

Method	Equation	Bias		Absolute Bias		Fit Index		Rank	Overall
		%	Rank	%	Rank	%	Rank	Sum	Rank
		5% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-2.32	1	15.99	2	92.08	4	7	2
	$\ln(H) = c_0 + c_1\ln(D)$	-2.56	3	16.03	4	91.94	5	12	5
	$H = c_0 + c_1\ln(D)$	-3.75	5	16.01	3	92.54	2	10	3
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.08	6	16.97	6	90.87	6	18	6
	$V = b_0 + b_1 D^2$	-2.66	4	16.23	5	92.88	1	10	3
	$\ln(V) = b_0 + b_1\ln(D)$	-2.51	2	15.96	1	92.15	3	6	1
		10% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-3.46	1	15.66	1	93.06	2	4	1
	$\ln(H) = c_0 + c_1\ln(D)$	-3.54	2	15.70	3	92.68	6	11	4
	$H = c_0 + c_1\ln(D)$	-4.57	6	15.79	4	93.02	3	13	5
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.43	5	15.98	6	92.83	5	16	6
	$V = b_0 + b_1 D^2$	-3.72	4	15.93	5	93.13	1	10	3
	$\ln(V) = b_0 + b_1\ln(D)$	-3.59	3	15.68	2	92.97	4	9	2
		20% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-3.50	1	15.48	2	93.25	4	7	1
	$\ln(H) = c_0 + c_1\ln(D)$	-3.50	2	15.52	3	93.03	6	11	4
	$H = c_0 + c_1\ln(D)$	-4.66	6	15.65	5	93.26	3	14	5
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.50	5	15.76	6	93.15	5	16	6
	$V = b_0 + b_1 D^2$	-3.53	3	15.65	4	93.41	1	8	3
	$\ln(V) = b_0 + b_1\ln(D)$	-3.59	4	15.47	1	93.26	2	7	1
		30% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-3.22	2	15.34	1	93.31	3	6	1
	$\ln(H) = c_0 + c_1\ln(D)$	-3.26	3	15.42	3	92.96	6	12	5
	$H = c_0 + c_1\ln(D)$	-4.39	6	15.54	5	93.24	5	16	6
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.25	5	15.53	4	93.35	2	11	4
	$V = b_0 + b_1 D^2$	-3.09	1	15.60	6	93.48	1	8	2
	$\ln(V) = b_0 + b_1\ln(D)$	-3.32	4	15.36	2	93.29	4	10	3
		40% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-3.49	1	15.38	1	93.34	3	5	1
	$\ln(H) = c_0 + c_1\ln(D)$	-3.51	2	15.44	3	93.05	6	11	4
	$H = c_0 + c_1\ln(D)$	-4.72	6	15.60	6	93.29	5	17	6
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.67	5	15.57	5	93.38	2	12	5
	$V = b_0 + b_1 D^2$	-3.57	3	15.53	4	93.49	1	8	2
	$\ln(V) = b_0 + b_1\ln(D)$	-3.59	4	15.39	2	93.32	4	10	3
		50% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-3.29	2	15.34	1	93.34	3	6	1
	$\ln(H) = c_0 + c_1\ln(D)$	-3.28	1	15.40	3	93.07	6	10	3
	$H = c_0 + c_1\ln(D)$	-4.50	6	15.55	6	93.30	5	17	6
Direct	$V = b_0 + b_1 D + b_2 D^2$	-4.46	5	15.51	4	93.39	2	11	5
	$V = b_0 + b_1 D^2$	-3.36	3	15.52	5	93.51	1	9	2
	$\ln(V) = b_0 + b_1\ln(D)$	-3.39	4	15.35	2	93.33	4	10	3

Table 5.--Evaluation statistics for different methods when the standard volume equation is the logarithmic equation

Method	Equation [1]	Bias		Absolute Bias		Fit Index		Rank Sum	Overall Rank
		%	Rank	%	Rank	%	Rank		
		5% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-0.93	1	15.78	3	92.34	3	7	1
	$\ln(H) = c_0 + c_1\ln(D)$	-1.15	2	15.75	2	92.19	4	8	3
	$H = c_0 + c_1\ln(D)$	-2.28	4	15.67	1	92.71	2	7	1
Direct	$V = b_0 + b_1 D + b_2 D^2$	-2.44	5	16.57	5	91.15	5	15	5
	$V = b_0 + b_1 D^2$	-1.28	3	16.19	4	92.96	1	8	3
		10% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-2.00	1	15.44	2	93.16	2	5	1
	$\ln(H) = c_0 + c_1\ln(D)$	-2.08	2	15.43	1	92.79	5	8	2
	$H = c_0 + c_1\ln(D)$	-3.06	5	15.45	3	93.10	3	11	4
Direct	$V = b_0 + b_1 D + b_2 D^2$	-2.80	4	15.66	4	92.94	4	12	5
	$V = b_0 + b_1 D^2$	-2.25	3	15.85	5	93.20	1	9	3
		20% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-2.05	1	15.24	2	93.34	2	5	1
	$\ln(H) = c_0 + c_1\ln(D)$	-2.06	2	15.24	1	93.10	5	8	2
Direct	$V = b_0 + b_1 D + b_2 D^2$	-3.15	5	15.29	3	93.32	3	11	4
	$V = b_0 + b_1 D^2$	-2.87	4	15.44	4	93.22	4	12	5
	$\ln(V) = b_0 + b_1\ln(D)$	-2.12	3	15.66	5	93.42	1	9	3
		30% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-1.78	2	15.19	1	93.37	3	6	1
	$\ln(H) = c_0 + c_1\ln(D)$	-1.82	3	15.20	2	93.02	5	10	3
	$H = c_0 + c_1\ln(D)$	-2.89	5	15.24	3	93.28	4	12	5
Direct	$V = b_0 + b_1 D + b_2 D^2$	-2.63	4	15.27	4	93.37	2	10	3
	$V = b_0 + b_1 D^2$	-1.72	1	15.68	5	93.45	1	7	2
		40% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-2.04	1	15.18	1	93.40	3	5	1
	$\ln(H) = c_0 + c_1\ln(D)$	-2.06	2	15.19	2	93.10	5	9	2
	$H = c_0 + c_1\ln(D)$	-3.20	5	15.25	4	93.33	4	13	6
Direct	$V = b_0 + b_1 D + b_2 D^2$	-3.01	4	15.23	3	93.41	2	9	2
	$V = b_0 + b_1 D^2$	-2.15	3	15.59	5	93.48	1	9	2
		50% Sample							
Indirect	$\ln(H) = c_0 + c_1/D$	-1.85	2	15.16	1	93.40	3	6	1
	$\ln(H) = c_0 + c_1\ln(D)$	-1.84	1	15.16	2	93.11	5	8	2
	$H = c_0 + c_1\ln(D)$	-2.99	5	15.22	4	93.34	4	13	5
Direct	$V = b_0 + b_1 D + b_2 D^2$	-2.82	4	15.18	3	93.42	2	9	3
	$V = b_0 + b_1 D^2$	-1.96	3	15.59	5	93.49	1	9	3

[1] Equation $\ln(H) = c_0 + c_1\ln(D)$ of the indirect method and equation $\ln(V) = b_0 + b_1\ln(D)$ of the direct method provided identical results and thus only results of the former are presented here.

Table 6.--Overall ranks of all methods by sampling proportion

Method	Equation	Sampling Proportion					
		5%	10%	20%	30%	40%	50%
------- Standard Volume Equation: $V = a + b\ D^2H$ -------							
Indirect	$\ln(H) = c_0 + c_1/D$	2	1	1	1	1	1
	$\ln(H) = c_0 + c_1\ln(D)$	5	4	4	5	4	3
	$H = c_0 + c_1\ln(D)$	3	5	5	6	6	6
Direct	$V = b_0 + b_1\ D + b_2\ D^2$	6	6	6	4	5	5
	$V = b_0 + b_1\ D^2$	3	3	3	2	2	2
	$\ln(V) = b_0 + b_1\ln(D)$	1	2	1	3	3	3
--- Standard Volume Equation: $\ln(V) = a + b\ \ln(D) + c\ \ln(H)$ ---							
Indirect	$\ln(H) = c_0 + c_1/D$	1	1	1	1	1	1
	$\ln(H) = c_0 + c_1\ln(D)$	3	2	2	3	2	2
	$H = c_0 + c_1\ln(D)$	1	4	4	5	5	5
Direct	$V = b_0 + b_1\ D + b_2\ D^2$	5	5	5	3	2	3
	$V = b_0 + b_1\ D^2$	3	3	3	2	2	3
	$\ln(V) = b_0 + b_1\ln(D)$	3	2	2	3	2	2

Forest Nutrition

Moderator:

Lee Allen

North Carolina State University

MID-ROTATION FERTILIZATION AFFECTS STEM FORM IN PLANTED SLASH PINE[1]

Eugene Shoulders, V. C. Baldwin, and Allan E. Tiarks[2]

Abstract.--Taper functions were fitted to optical dendrometer measurements of stem profiles of 35 fertilized and 50 unfertilized permanent sample trees in a mid-rotation fertilizer experiment in a slash pine (Pinus elliottii Engelm. var elliottii) plantation in southwest Louisiana. Sample tree diameter at breast height (d.b.h.), total height, and height to fixed upper bole diameters (o.b.) in 2-inch decrements were measured when fertilizer was applied at age 13 years and at 16, 19, and 22 years. Sample trees were distributed proportionately among diameter classes at age 13. On average, fertilizer increased 9-year d.b.h. growth of sample trees by 1.3 inches and 9-year height growth by 4.7 feet. There were no significant pretreatment differences between taper equations for fertilized and unfertilized trees. From age 13 to 19 years, boles of fertilized trees tended to become more cylindrical than boles of unfertilized trees, resulting in a significant difference between taper equations at age 19. Differences between fertilized and unfertilized trees in height and radial growth rates resulted in higher d.o.b. at 17 feet/d.b.h. ratios for fertilized than for unfertilized trees at age 22 years.

INTRODUCTION

What effect, if any, does fertilization have on bole form of individual trees in southern pine plantations? This question is basic to the accurate determination of short-term responses of trees to fertilizer and to the development of growth and yield models for predicting development of fertilized plantations. If fertilizer alters the partitioning of photosynthate into xylem tissue along the trees' boles, these changes must be reflected in volume estimates if response to fertilizer is to be accurately estimated and modeled.

This paper reports taper functions at ages 13, 16, 19, and 22 years for fertilized and unfertilized permanent sample trees in a fertilizer experiment in an unthinned slash pine (Pinus elliottii Engelm. var elliottii) plantation in southwest Louisiana. In the experiment, both diameter at breast height (d.b.h.) and height growth were increased by fertilization (Shoulders and Tiarks 1980). Moreover, estimates by the height-accumulation procedure (Grosenbaugh 1954) indicated that fertilized plots produced 25 percent more bole volume than unfertilized plots in 9 years following treatment. The analysis of taper functions was undertaken to compare bole geometry over time of fertilized and unfertilized trees.

MATERIALS AND METHODS

The study compared no fertilization to a single combined application of 360 pounds/acre of nitrogen, 85 pounds/acre of phosphorus, and 57 pounds/acre of potassium when the plantation was 13 years old. The nitrogen came from ammonium nitrate, the phosphorus from triple super phosphate, and the potassium from muriate of potash. The fertilizer was broadcast on the surface in a 2-foot-wide band between the rows of trees.

Initial planting spacing in the plantation was about 7 by 9 feet. The surviving stand at 13 years averaged 572 trees/acre, with a mean d.b.h. of 4.9 inches and a mean basal area of 74 ft^2/acre. Heights of dominant and codominant trees averaged 38 feet, indicating a site index for slash pine of 65 feet (base age 25).

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

[2] Principal Silviculturist, Principal Mensurationist, and Principal Soil Scientist, respectively, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

Treatments were replicated three times in a randomized plot design. Twenty permanent sample trees were selected on each plot when the fertilizer study was established. These trees were distributed proportionately among diameter classes. Diameter at breast height (d.b.h.) of each tree was measured to the nearest 0.1 inch and total height to the nearest 1 foot. In addition, heights to successively smaller, even 2-inch outside-bark diameters (d.o.b.) were determined with an optical dendrometer for the entire bole of each permanent sample tree.

These measurements were repeated at ages 16, 19, and 22 years on 35 of the original fertilized trees and on 50 of the original unfertilized sample trees. The trees were distributed among initial d.b.h. classes as follows:

d.b.h. class at 13 years	Fertilized trees	Unfertilized trees
inches	percent	
3	3	2
4	28	32
5	46	40
6	17	20
7	6	6
Total	100	100

The taper model of Kozak and others (1969) was selected and fitted to data from each treatment at each measurement to characterize stem form. This model was chosen over the others tried because it adequately fit the upper bole data where changes due to fertilization occurred, and too few measurements were made of the boles below breast height to develop separate relationships for their basal 4.5 feet. The formula for this model is

$$D^2/DBH^2 = b_1(H/TH-1) + b_2(H^2/TH^2-1),$$

where:

DBH = diameter at breast height (inches),

TH = total tree height from groundline to tip (feet),

H = height from groundline corresponding to D (feet),

D = diameter (outside bark) corresponding to H (inches), and

b_1 and b_2 = regression coefficients estimated from the sample tree data.

Equations were tested by analyses of covariance for differences between treatments and for differences due to age of the plantation. Significance was preset at the 0.05 level.

RESULTS

Covariance analyses of data from unfertilized sample trees showed that plantation age significantly affected taper relationships. Therefore, separate taper equations were computed for fertilized and unfertilized trees at each age (i.e., 13, 16, 19, and 22 years)(table 1).

Equations for fertilized and unfertilized trees did not differ significantly from each other at ages 13, 16, and 22 years. But differences between the two equations were significant at age 19.

A plotting of predicted stem profiles of fertilized and unfertilized trees of average height and diameter at ages 13, 16, 19, and 22 suggests a gradual change in taper over time and reinforces the notion that fertilizer did alter bole development during this period (fig. 1). At age 13, trees that were scheduled to be fertilized were smaller in diameter at a given height than check trees of the same d.b.h. and total height. At age 16, stem profiles of fertilized and unfertilized trees of the same d.b.h. and total height were essentially identical, indicating that fertilized trees had increased in upper stem diameter more rapidly than unfertilized trees. This trend persisted at age 19 and resulted in taper functions for fertilized and unfertilized trees that were significantly different. The curves for this age indicate that fertilization decreased taper in the lower bole and increased taper in the upper bole of trees having the same d.b.h and total height. However, the change in form was apparently a temporary phenomenon because age 22 stem profiles of fertilized and unfertilized trees of like d.b.h. and height were remarkably similar.

In the 9 years following treatment, fertilized sample trees grew 1.3 inches more in d.b.h. and 4.7 feet more in total height than unfertilized trees. Thus, comparisons between trees of like d.b.h. and total height do not adequately address the question--did fertilizer cause stems to become more cylindrical? To investigate this relationship, we solved the taper equations for 16-, 19-, and 22-year-old trees for a series of D (upper stem)/d.b.h. ratios, using current average d.b.h.'s and total heights of trees that were grouped by 1-inch d.b.h. classes at age 13. At comparable heights above the ground, the ratios for fertilized trees were consistently greater than ratios for unfertilized trees.

Table 1.--Regression coefficients and test of significance of taper equations for fertilized and unfertilized sample trees, by plantation age[1]

Plantation age	Unfertilized trees		Fertilized trees		F-value	
	B_1	B_2	B_1	B_2		
years						
13	-1.31142	0.140068	-1.44969	0.263401	2.74	NS
16	-1.40978	0.282480	-1.36218	0.242642	0.30	NS
19	-1.51277	0.374889	-1.31228	0.202642	9.16	*S
22	-1.39332	0.281958	-1.42352	0.314496	0.96	NS

[1] NS = not significant; S = significant.

Taper in the first log is of particular interest to foresters because volume and value are concentrated in this segment of the stem. Taper in the butt log is commonly reported in Girard Form Class units: the ratio diameter inside bark (d.i.b.) at 17.3 ft/d.b.h. expressed as a percentage. Because d.i.b.'s were not measured in this study, we computed the ratio of d.o.b. at 17.3 feet to d.b.h. and determined the change in the ratios for fertilized and unfertilized trees during the 9-year period (table 2).

Table 2.-- D.o.b. at 17.3 feet/d.b.h. ratios of fertilized and unfertilized trees by initial d.b.h. class

Initial d.b.h.	Ratio at 22 years		Difference
	Unfertilized trees	Fertililized trees	
inches	percent		
4	83.0	84.5	1.5
5	85.0	86.2	1.2
6	86.4	86.5	0.1
7	86.7	88.1	1.4

The data show a 9-year improvement in the ratio due to fertilization of 1.5 percentage points for trees that were 4 inches d.b.h. initially, 1.2 percentage points for 5-inch trees, 0.1 percentage point for 6-inch trees, and 1.4 percentage points for 7-inch trees. In Mesavage's (1947) tables for estimating cubic foot volume of timber, each percentage point increase in Girard Form Class corresponds to an increase of about 3 percentage points in the total volume of trees of equal d.b.h. and merchantable height.

The impact of fertilization on taper relationships apparently peaked at about age 19 -- 6 years after fertilizer was applied. We adopted a worst case scenario to evaluate the potential effect of differences in stem form on estimated response to fertilizer during this 6-year period: the case whereby volumes of fertilized sample trees at age 19 were derived from the unfertilized-tree taper function rather than from the fertilized-tree taper function. The two sample tree volume estimates were expanded to per-acre values by multipling sample-tree volume/basal area ratios by basal area per acre on fertilized plots. The same procedure was used to expand fertilized sample-tree volumes at age 13 to per-acre values. This procedure was mandated by the fact that the only total heights measured in this study were those of sample trees. Periodic cubic-foot growth per acre was computed by subtracting age 13 volumes from age 19 volumes.

These computations showed that the 6-year periodic survivor growth estimate based on the unfertilized-tree taper functions was 95 ft^3/acre, or 4.3 percent less than the estimate based on the fertilized-tree taper function.

The procedure outlined above was also used to determine the effects of taper differences on estimation of stand volume at 19 and 22 years. For fertilized plots at age 19, volume estimate based on the unfertilized-tree taper function was 2.9 percent less than the estimate based on the fertilized-tree taper function. At age 22, the volume estimate based on the unfertilized-tree taper function was 52 ft^3/acre, or 1.3 percent higher than that based on the fertilized-tree taper function.

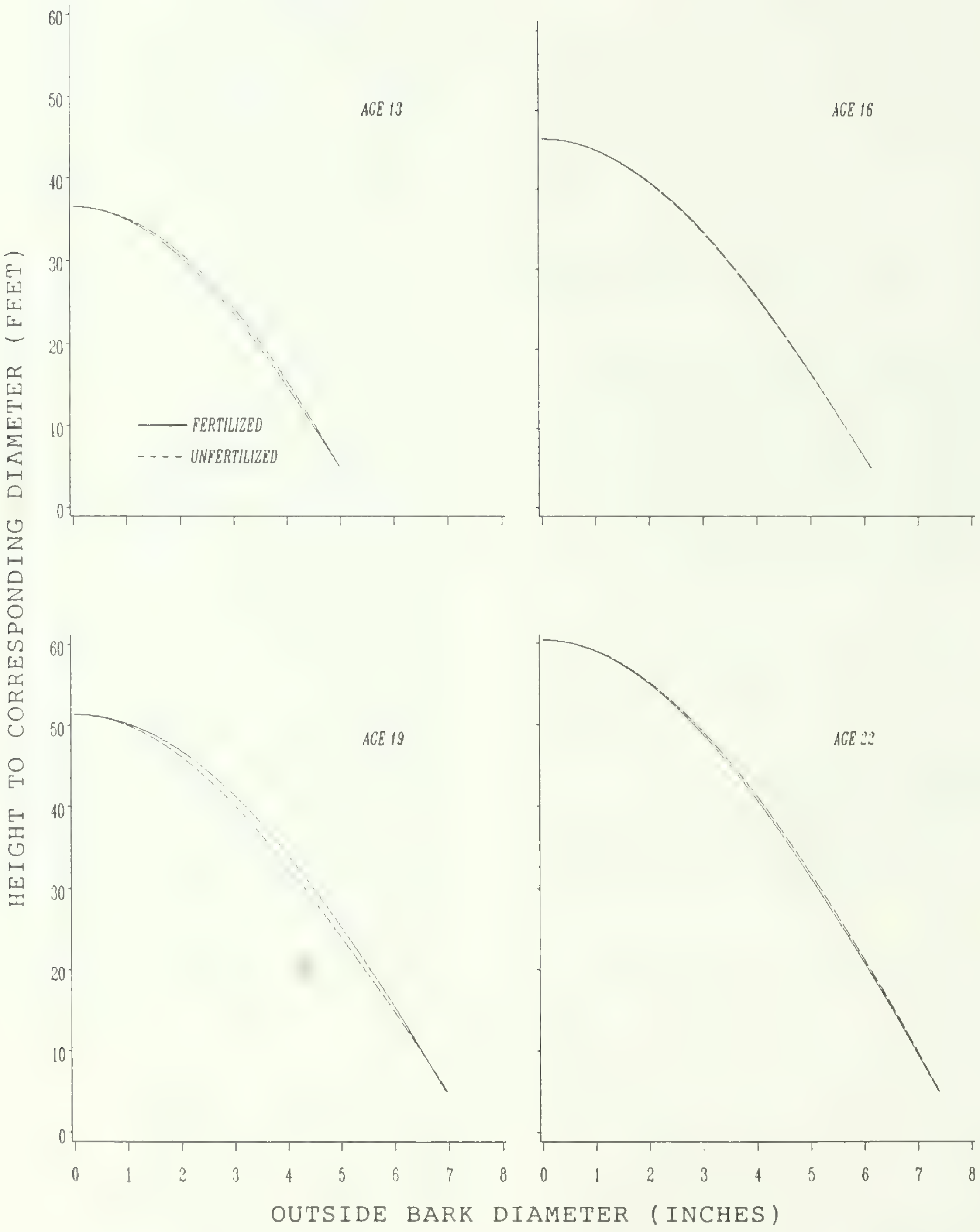

Figure 1.--Predicted stem profiles of unfertilized and fertilized trees of average size at ages 13, 16, 19, and 22 years.

SUMMARY AND CONCLUSIONS

Taper functions were fitted to permanent sample tree data from an unthinned slash pine plantation to determine the extent to which changes in stem form contributed to a 25 percent increase in periodic cubic volume growth due to fertilization. Independent of its effect on d.b.h. and height growth, fertilization at age 13 caused lower boles of trees to become more cylindrical and increased taper in the upper bole.

Fertilizer effects on stem form culminated in about 6 years, and taper equations for fertilized and unfertilized trees were no longer significantly different from each other at age 22 years.

Computations of stand volume based on these taper functions indicate that about 13 percent of the 6-year response to fertilizer may have accrued from changes in stem form. This may be sufficient incentive for some to consider the effects of fertilizer on stem form in evaluating the immediate response of plantations to added nutrients. Those whose primary objective is to inventory the volume of timber in a stand at a particular point in time may be little concerned about the effects of treatment on stem form because our worst case scenario showed a maximum difference of less than 3 percent between estimates of standing volume based on fertilized tree taper functions and those based on unfertilized tree functions.

Two issues emerged from this exercise that require further study. They are: to what extent will thinning alter the effects of fertilizer on stem form, and how can age effects on stem form be incorporated into models for predicting growth response of stands to treatments that alter growth/age relationships?

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CHANGES IN PATTERN OF STEM GROWTH IN POLE-SIZED LOBLOLLY PINE AFTER SEWAGE SLUDGE APPLICATION[1]

William H. McKee, Jr.[2]

Abstract.--Applying 450 or 900 pounds of nitrogen per acre in sewage sludge to a 28-year-old thinned loblolly pine plantation on the upper Coastal Plain increased diameter growth more in upper stems than in lower stems over the next 4 years. Stem taper, therefore, was reduced by applying sludge, but the change in a limited number of sample trees was not sufficient to produce a statistically significant difference between carefully measured volumes and volumes computed with a single formula for treated and untreated trees.

INTRODUCTION

Jack et al. (1988) reported that fertilizer applications alter the form class of pole-sized loblolly pines and suggested that using a single volume equation for fertilized and unfertilized plots would result in substantial underestimation of volume response to treatment. Various studies have indicated that fertilizing stimulates growth more in upper than in lower stems. McKee et al. (1986) reported diameter and volume growth responses to application of sewage sludge to a 28-year-old loblolly pine (*Pinus taeda* L.) stand on the upper Coastal Plain in South Carolina. An increase in diameter growth in the 4 years after treatment was statistically significant, but an increase in volume growth computed with conventional volume equations was not.

I wondered if the phenomenon described by Jack et al. (1988) might be responsible for this apparent inconsistency. The study described here was designed to examine that possibility.

METHODS AND MATERIALS

The study was conducted at the Savannah River Plant near Aiken, SC, on an upper Coastal Plain terrace with a long agricultural history. Loblolly pine had been planted on the site 28 years before treatment. Soil is Orangeburg loamy sand (*Typic Paleudult*, fine-loamy siliceous, thermic), which is quite common and support large areas of forest on the upper Coastal Plain. The series is well to slightly excessively drained, has a pH of 5 to 5.5, contains 200 to 500 parts per million of total N in the surface 4 inches, and has a cation exchange capacity of 0.01 to 0.02 moles per 2.2 pounds throughout the profile.

Initial planting spacing had been 6 by 10 feet, and the stands had been heavily thinned at age 20, leaving 169 to 212 trees per acre. In July 1981, when the stand was 29 years old, sewage sludge was sprayed onto 1/2-acre treatment plots at rates 0, 450 and 900 pounds of N per acre. Other sludge constituents have been described by Wells et al. (1984) and McKee et al. (1986).

Measurement plots were 0.20 to 0.30 acre and contained 16 to 35 trees. Tree heights were measured biennially beginning in early 1981, and diameters at breast height (d.b.h) were measured annually. From each of the three treatments, eight trees were destructively sampled 4 years after treatment. Trees were collected from the four sides of two plots for each treatment. The range in d.b.h/ of each plot was used to select sample trees in that plot that represented the sizes of trees on the plot.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Trees were cut within 3 inches of groundline, and stems were cut into 6-foot bolts. Diameters were measured at the bottom of each bolt, and disks were collected at 12-foot intervals in the stem for analysis of diameter growth. Diameter growth rates inside bark were determined at 6, 18, 30, 42, and 54 feet up the stems. Values then were expressed as fractions of initial inside-bark diameters and basal areas.

Equations were:

$$\text{Diameter growth} \quad \frac{\text{Final Diameter} - \text{Initial Diameter}}{\text{Initial Diameter}}$$

$$\text{Sectional area growth} \quad \frac{\text{Final Area} - \text{Initial Area}}{\text{Initial Area}}$$

Volumes of bolts were calculated from the averaged diameters of the top and bottom of each bolt and the bolt length. Top sections were treated as cones in volume computation. Total stem volumes were obtained by summing the values of components. Volumes also were estimated from equations developed for Piedmont and lower Coastal Plain loblolly pine (Bailey and Clutter 1970). The same equations were used for treated and untreated trees.

RESULTS AND DISCUSSION

As expected, the increases in relative diameter and cross-sectional area growth rose with height in the stem (Figures 1 and 2). Responses to 900 pounds of sludge were the same as responses to 450 pounds of sludge per acre over the 4 years after application. Sludge is, in effect, a slow release fertilizer. It therefore is possible that advantages from the heavier sludge application will appear in the future. Meanwhile, the differences in diameter and cross-sectional area responses with tree height are what Jack et al. (1988) might have predicted.

The changes in stem form did not significantly influence volume computations, however. Carefully measured volumes did not differ significantly from volumes calculated with Bailey and Clutter's (1970) formula.

I believe that the changes in stem form suggested by Figures 1 and 2 did occur, and that they would be reflected in volume calculations in a sufficiently large sample. Our failure to detect them in the study described, however, suggests that they were not of practical significance over the 4-year response period. Since sewage sludge releases nutrients slowly over an extended period, differences of practical importance may be forthcoming and changes in stem form may have to be considered when effects of sludge application are measured.

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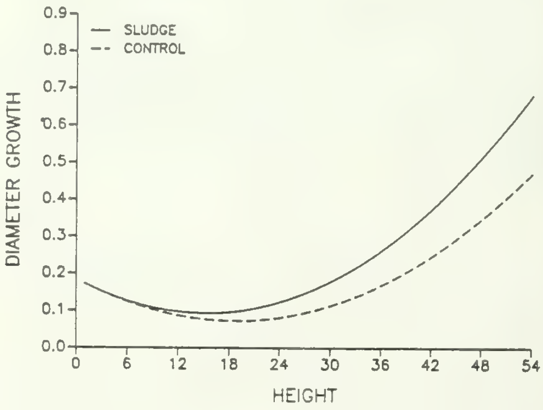

Figure 1.--Plot of diameter and height ratios for control and sludge treated tree stems.

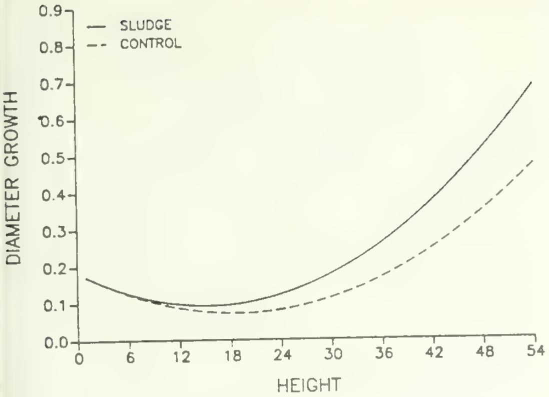

Figure 2.--Plot of basal area and height ratios for control and sludge treated tree stems.

Table 1.--Comparison of measured versus computed volumes of tree stems four years after sludge (outside diameter)

Sludge Treatment	Stem Volume Measured	 Piedmont Equation	
	---cubic feet---		
None	11.47	11.95	
	19.55	18.22	
	23.95	21.47	
	3.30	3.02	
	18.69	15.22	
	3.24	3.10	
	23.49	22.61	
	8.85	8.40	
Average	14.07	13.00	
Difference in measured and calculated volume			-1.17
Low	22.35	21.05	
	5.39	4.53	
	31.10	30.34	
	11.76	11.17	
	58.19	50.71	
	30.82	26.52	
	35.45	32.27	
	17.08	15.05	
Average	26.50	23.95	
Difference in measured and calculated volume			-2.55
High	14.00	17.73	
	43.14	32.50	
	3.33	5.64	
	33.21	26.89	
	13.85	13.19	
	19.78	20.47	
	32.69	31.04	
	44.56	40.16	
Average	25.57	23.45	
Difference in measured and calculated volume			-2.11

IMPACT OF SOUTHERN PINE BEETLE INFESTATION ON NUTRIENT RETENTION MECHANISMS IN LOBLOLLY PINE[1]

Thomas M. Williams, Charles A. Gresham, Roy L. Hedden,
and Elizabeth R. Blood[2]

Southern pine beetles (Dendroctonous frontalis) cause the death of several thousand hectares of loblolly pine forest annually. Tree mortality is caused by a symbiotic association of the beetle with blue- stain fungi (Ceratocystis spp.) which destroy tree connective tissues. Nutrient flows in throughfall, stemflow, and groundwater were determined in an infested 20-year-old loblolly pine stand and an uninfested control. Throughfall nitrate concentrations in the infested stand were elevated one week after infestation but dropped below control concentrations following leaf fall in the second week. Stemflow nitrate concentrations in the infested stand exceeded controls four weeks after infestation. Concentrations in groundwater were elevated above control six weeks after infestation. Stemflow orthophosphate concentrations in the infested stand remained an order of magnitude higher from one week after infestation until the end of sampling.

INTRODUCTION

Forest nutrient cycles seem disproportionately disturbed by infestations of defoliating insects. Swank and others (1981) found a significant increase in nitrate in stream water despite oak defoliation on only a part of the watershed. Fogel and Slansky (1985) showed pine sawfly (Neodiprion sertifer) defoliation of Scots pine (Pinus sylvestris) resulted in a 192% increase in nitrogen release when compared to normal litterfall. Kimmins (1972) estimated sawfly defoliation of pine would increase contributions to litterfall by 165% for nitrogen, 133% for phosphorus, and 157% for potassium.

Over the past ten years southern pine beetles have been the prime cause of loblolly pine mortality in the Southeast (Sheffield and others, 1985). Rapid tree mortality is due to symbiosis between the beetle and blue stain (Ceratocystis spp.) fungi (Basham 1970). Beetles act as a vector for the fungus. As beetles bore to the tree cambium they also deposit fungal spores on the wood. These spores develop into the fungus which then spreads through the ray cells and infects the entire xylem system (Caird 1935). Reduction of xylem pressure also decreases the ability of the tree to repel further beetle attack. The tree finally dies through desiccation.

Loblolly pine is able to attain rapid growth on poor soils due to efficient internal cycling mechanisms. Switzer and Nelson (1972) showed internal translocation provided over 60% of the phosphorus needed for growth. Metz and Wells (1965) also found translocation of 50% of nitrogen and 60% of potassium from needles prior to abscission. Tree mortality in southern pine beetle attacks is caused by disruption of internal moisture movement and would also be expected to disrupt normal nutrient cycling.

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[1] Paper presented at Fifth Biennial Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] We would like to thank Jud Alden, Kelly Hargrave, Clara Jackson, Bill Johnson, and Lou Jolley for dedicated field and laboratory work connected with this study. Funding for a portion of the study was from the National Science Foundation grant #BSR 8415935

In this study we investigated nutrient movements in throughfall, stemflow, and within the shallow groundwater in a twenty-year-old loblolly stand attacked by southern pine beetles. The stand was compared to a nearby control stand of about the same age, density, and soil type. We tested the hypothesis that disruption of internal cycling in the beetle infested stand would increase the rate of nutrient leaching.

METHODS

On May 28, 1985 southern pine beetles attacked a stand of 20 year old loblolly pine about 1 kilometer west of a nutrient cycling study on Hobcaw Barony in Coastal South Carolina. The beetle infested stand was well paired to that study stand in age (20-25 years), soil type (Typic haplaquods), and basal area ($25m^2ha^{-1}$). We used the long term nutrient cycling stand as a control and installed instrumentation in the infested stand to measure nutrient transfers in throughfall, stemflow, and concentrations in the water table aquifer. On such poorly drained soils the water table is near the bottom of the B horizon and receives leachate directly from that horizon.

Throughfall was collected in 20 randomly located 1864 cm^2 troughs; in the control stand and 10, 3036 cm^2 troughs in the infested stand. Stemflow was collected by installing aluminum collars around ten trees in the infested stand. These ten trees were chosen to be of the same diameters as 10 of the 14 trees with collars in the control stand. Groundwater was sampled by 10 shallow groundwater wells in each stand. Each well was a 3 meter (5 meter in infested stand) by 5 cm diameter PVC pipe screened by drilling 2mm holes throughout the length of the pipe.

After each storm, water was collected from each sampler and returned immediately to the laboratory. Hydrogen ion concentration was determined upon arrival with an Orion pH meter. Nitrate + nitrite N and orthophosphate were determined within 24 hours using cadmium reduction (Technicon Industrial Method No. 158-71W) and by ascorbic acid reduction (Technicon Industrial Method No.99-70W) respectively. NH_4 was determined within 4 days (Technicon Industrial Method No. 154-71W). A subsample was refrigerated for later analysis for Na, Ca, Mg, and Na (atomic absorption).

RESULTS

The rate of beetle development and tree mortality is dependent on temperature (Mizell and Nebeker, 1978). Although rain events were recorded by date, discussion is more meaningful when expressed as a stage of spot development. Spot development was recorded using the three stages of development outlined in A Field Guide for Ground Checking Southern Pine Beetle Spots (USDA 1980).

Stage One

Southern pine beetles generally attack the mid-bole initially. The tree resists this attack with a flow of resin that produces a tube of pitch at the point of attack. Pitch flow during this stage appears white or pink and is soft and sticky. If the tree has little resin flow these tubes are not easily seen. During this initial stage of attack xylem tissues have not yet been damaged to the point of causing needle discoloration.

Stage Two

When beetles successfully enter the tree they begin to produce pheremone attractants. Large numbers of beetles are then attracted to the tree. Adults bore into the tree producing S-shaped galleries between the bark and wood. Blue stain spores rub off the beetles and infect the tree along these galleries. At this stage the foliage begins to turn yellow, then red. If the bark is removed adults, eggs,or immature beetles can be found in the galleries. Secondary infestations of other bark beetles and wood borers often occur producing piles of white frass at the tree base.

Stage Three

By the time the southern pine beetle brood matures blue stain has killed the tree. The foliage has turned red or fallen from the tree. The bark is loose and the beetle galleries are obscured by frass of other boring insects. Secondary infestations of several boring insects or termites are common. In stage three trees larvae or pupae of clerid beetles (a major predator of the southern pine beetle) can often be found.

Hydrologic Changes

Beetle infestation did not produce large changes in the volume of water moving through each stand. Throughfall volumes were not significantly different in the infested and control stands despite the small errors associated with these estimates (fig. 1). Stemflow volumes were quite small for both stands representing less than 1mm of precipitation on several storms. Groundwater flow rates were not determined. However, late in stage three lowered evapotranspiration in the infested stand would be expected to result in a higher water table and enhanced groundwater movement. Lack of difference in hydrology between the stands indicates any difference due to infestation would be as a result of changes in nutrient concentrations.

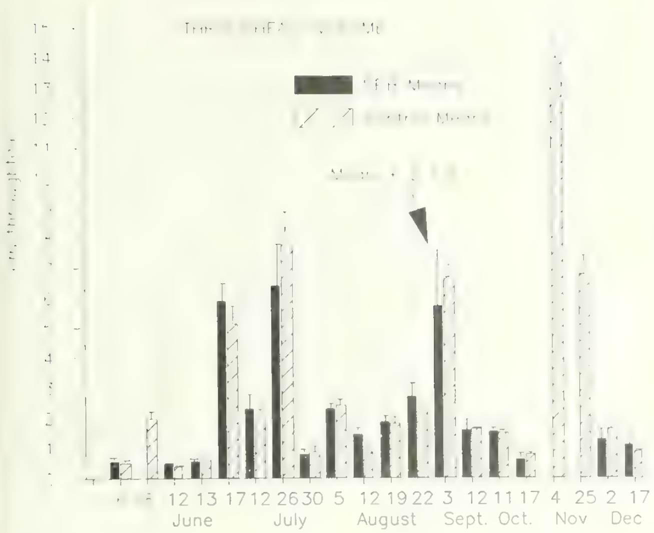

Figure 1. Mean throughfall volumes of measured storms.

Nitrogen

Nitrogen movements were measured as both nitrate and ammonium. Ammonium values were variable and showed significant differences only in groundwater. Nitrate concentrations in throughfall were higher in the infested stand only in the first storm of stage one (fig. 2). By stage three throughfall nitrate was significantly lower in the infested stand than in the control.

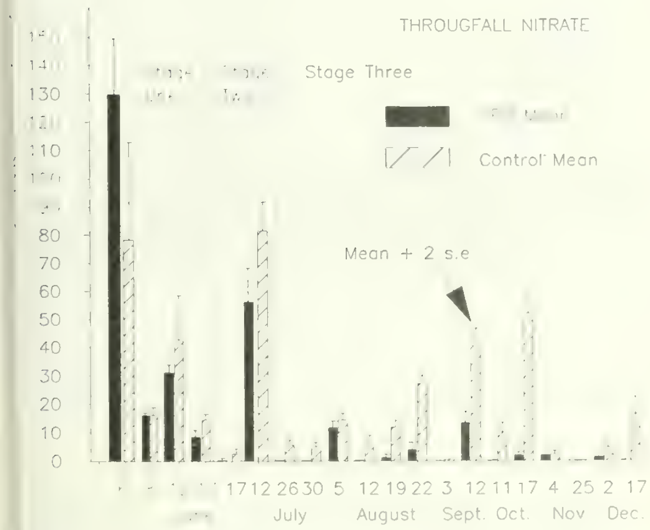

Figure 2. Mean nitrate - N concentrations in throughfall measured in beetle infested stand and nearby unaltered control.

Stemflow nitrate showed the same pattern but higher values in the infested stand extended through stage two (fig.3). Groundwater nitrate was higher in the infested stands late in stage two and into stage three although higher variability in groundwater allows little statistical confidence in the large difference (fig. 4).

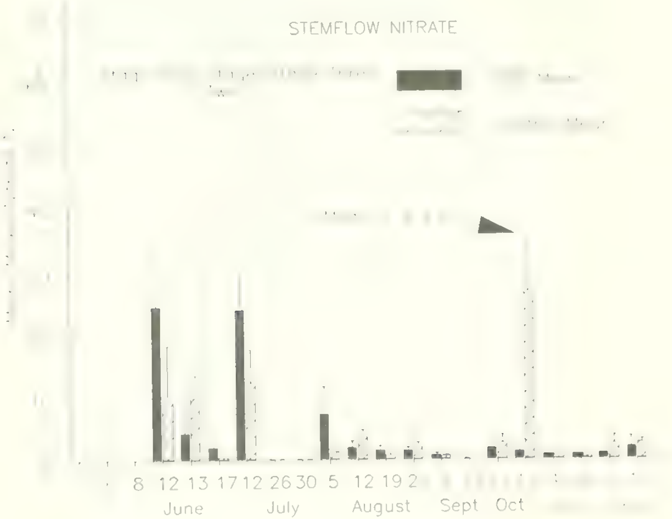

Figure 3. Mean nitrate - N concentrations in stemflow measured in beetle infested stand and nearby unaltered control.

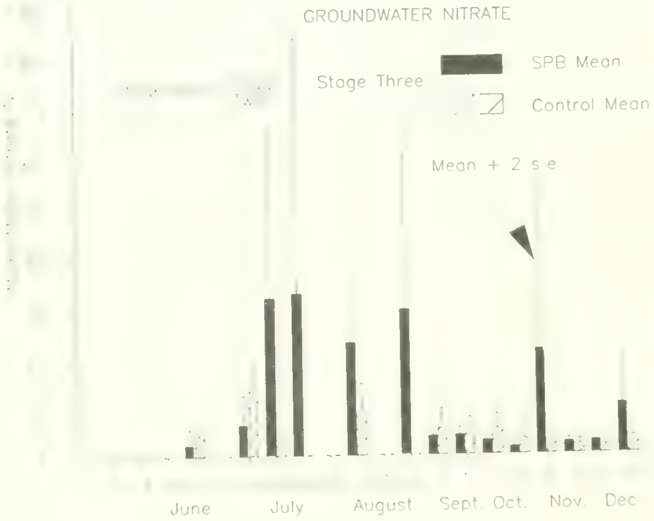

Figure 4. Mean nitrate - N concentrations in groundwater measured in beetle infested stand and nearby unaltered control.

Phosphorus

Phosphate concentrations in throughfall were not similar to nitrate. The infested stand showed equal or smaller phosphate concentrations throughout stages one and two and only showed increased concentrations in stage three (fig. 5). The increased concentration occurs primarily during and after the needles had fallen from the infested trees. Stemflow concentrations may explain that result because stemflow phosphate was an order of magnitude greater in the infested stand for several months into stage three (fig. 6). It may be that splash from the branches and boles was responsible for the increased concentrations in throughfall. Groundwater concentrations showed none of the increase seen in throughfall or stemflow. In fact, the control phosphate concentrations were above the infested stand in November and December (fig.7).

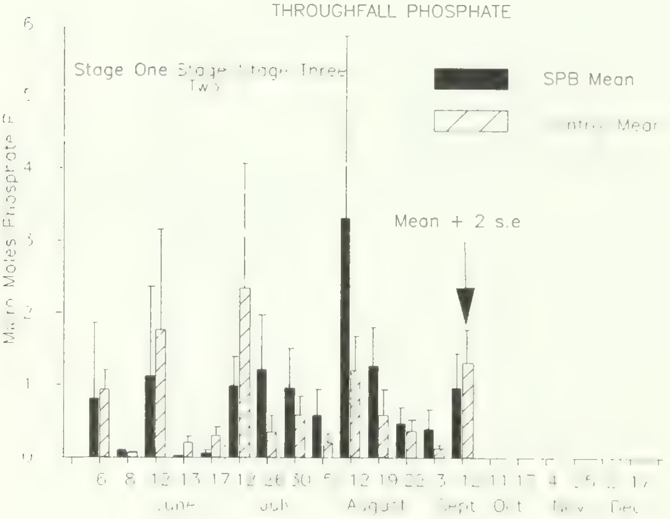

Figure 5. Mean phosphate- P concentrations in throughfall measured in beetle infested stand and nearby unaltered control.

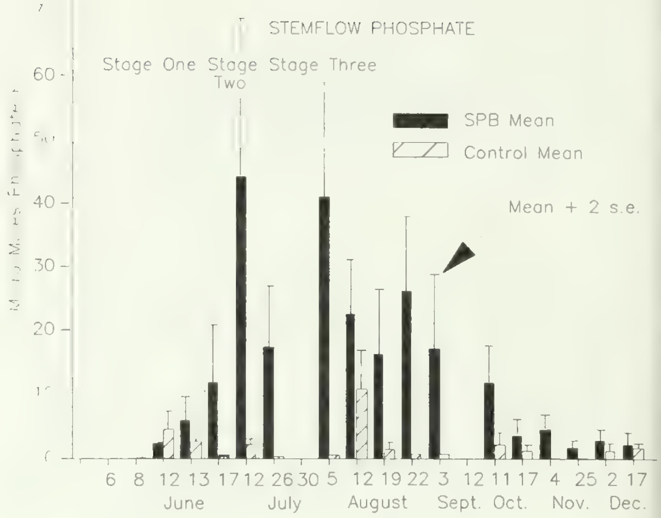

Figure 6. Mean phosphate - P concentrations in stemflow measured in beetle infested stand and nearby unaltered control.

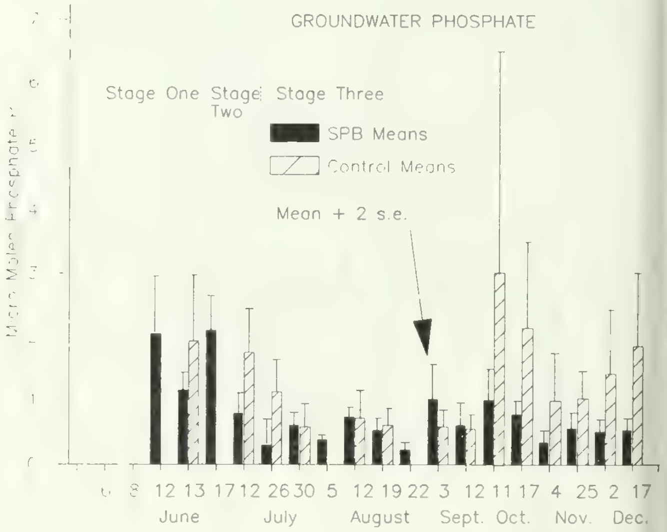

Figure 7. Mean phosphate - P concentrations in groundwater measured in beetle infested stand and nearby unaltered control.

Potassium

Potassium concentrations are consistently and significantly higher in the infested stand in both throughfall (fig. 8) and stemflow (fig. 9) with stemflow concentrations about five times larger. However, groundwater concentrations were not different and considerably less than either throughfall or stemflow (fig. 10).

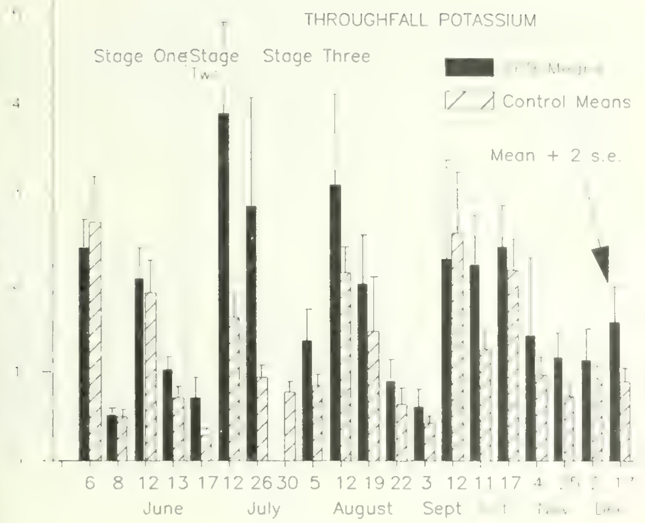

Figure 8. Mean potassium concentrations in throughfall measured in beetle infested stand and nearby unaltered control.

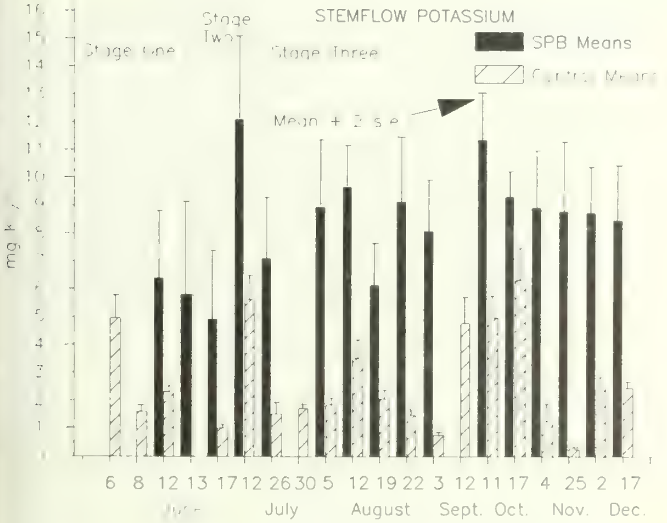

Figure 9. Mean potassium concentrations in stemflow measured in beetle infested stand and nearby unaltered control.

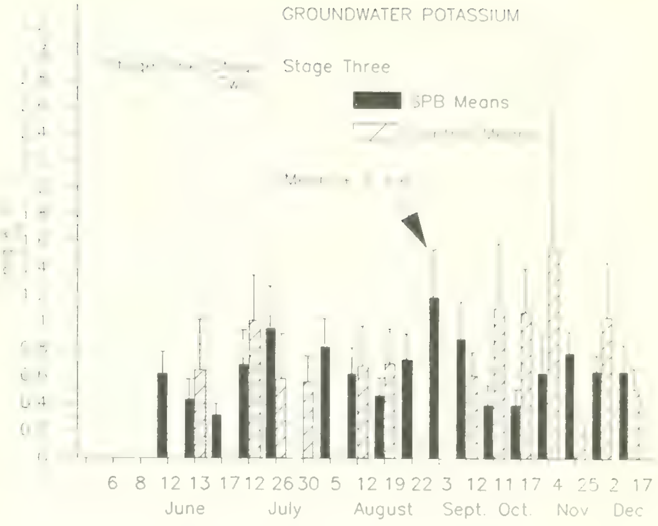

Figure 10. Mean potassium concentrations in groundwater measured in beetle infested stand and nearby unaltered control.

Magnesium

Concentrations of magnesium, sodium, calcium, and hydrogen ion behaved similarly. Throughfall concentrations in the infested stand were similar or higher in the early part of stage one but were consistently lower than the controls throughout stage two and three (fig.11).
Stemflow concentration pattern was similar with slightly higher values in the infested stand in stage one but with consistently higher values in the control from late in stage two to the end of the study (fig. 12). Ground water concentrations were consistently higher on the control stand (fig. 13).

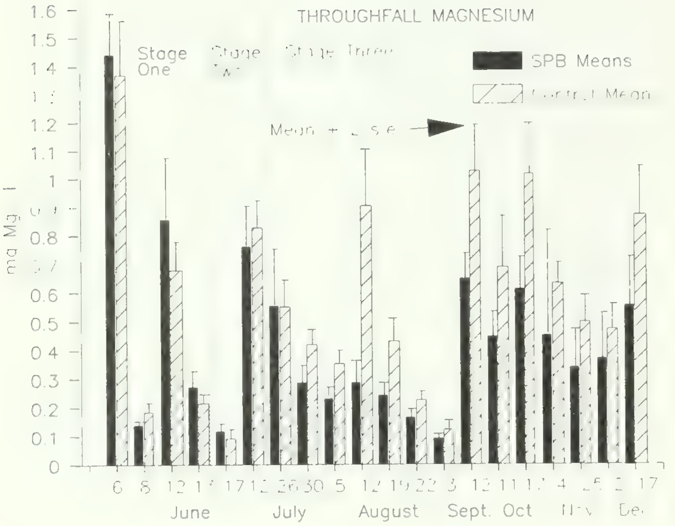

Figure 11. Mean magnesium concentrations in throughfall measured in beetle infested stand and nearby unaltered control.

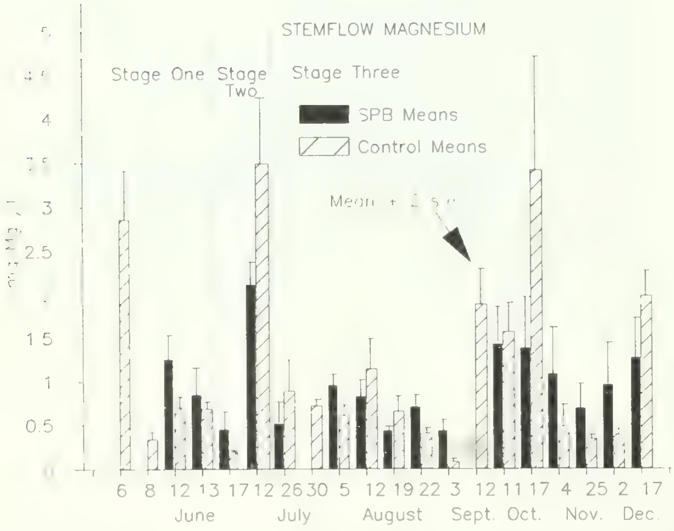

Figure 12. Mean magnesium concentrations in stemflow measured in beetle infested stand and nearby unaltered control

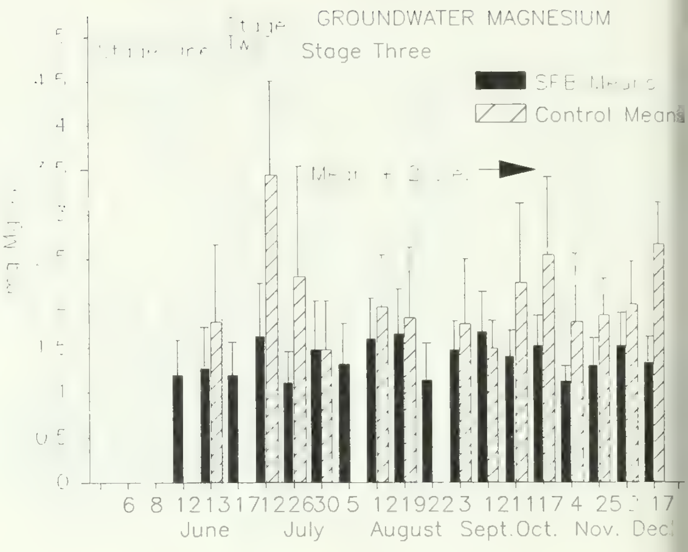

Figure 13. Mean magnesium concentrations in groundwater measured in beetle infested stand and nearby unaltered control.

Data Compilation

A summary of the results are shown in figure 14. The results of all elements were graphed as shown in figures 2 - 13. Since these figures are essentially storm by storm 't' tests of the hypothesis of no difference between treatments they were used to interpret changes in each stage of infestation. The plus, minus, zero or "nd" indications in the table were determined by a qualitative inspection of the figures. In addition a two way analysis of variance was done for each element. The classes used in this analysis were treatment (infested vs. control) and storm. The column marked "all" contain a "t" or "s" if treatment or storm was significant in the analysis (95%). Significant treatments are self explanatory. Significant storm effects may be caused by volume differences, season, or interaction with stage of infestation.

	THROUGHFALL				STEMFLOW				GROUNDWATER			
Stage	1	2	3	All	1	2	3	All	1	2	3	All
NO3	+	0	-	S	nd	+	-		nd	nd	+	
NH4	nd	-	nd	T	nd	-	0		nd	0	+	
PO4	nd	nd	+	S	nd	+	+	T	nd	0	-	T
K	0	+	+	T	nd	+	+	T,S	nd	-	-	
Ca	-	-	-	T,S	nd	nd	nd		nd	nd	-	
Mg	0	0	-	T,S	nd	+	-	S	-	-	-	
Na	-	-	-	S	0	0	-	S	nd	nd	-	T
H^+	-	-	+		nd	nd	-	S	nd	nd	-	T

Figure 14. Summary of concentration changes in beetle infested stand. Plus signs indicate larger concentrations in the infested stand. Minus signs indicate larger concentrations in the control stand. Zero's in dictate no change. blocks with "nd" indicate no data or no discernible difference due to variability. The "all" column indicates results of a two way (treatment by storm) anova. A "t" in this column indicat significant (95%) treatment effects across all storms and an "s" represents significant storm effects.

DISCUSSION

The results of this study suggest beetle infestation changed nutrient movements in these stands by two mechanisms. The direct effect of beetle induced mortality increased leaching of biologically active nutrients (N, P, K) from needles and primarily bark. The indirect effect of defoliation seems to have decreased the elements (Na, Mg, H^+) associated with impaction of aerosols.

Nitrate nitrogen showed differences between stands. Throughfall nitrate was higher early in the infestation but dropped below the control at or before defoliation. Potassium concentrations were higher in the infested stand throughout the studied period. Phosphate values were also higher in the infested stand after defoliation. Both these nutrients showed large increases in stemflow and it seems most likely that splash from the branches enriched throughfall phosphate and potassium. Beetle infestation seems to have either blocked transport of these nutrients or enhanced leaching by rapid decomposition.

Nitrate and ammonium nitrogen showed an increase in groundwater although this was obscured by variability for nitrate. The timing of the increase would suggest a pulse of material moving through the soil. Alternatively, increases could be associated with cessation of uptake or death and decomposition of root material. Phosphate and potassium were retained in the forest floor or upper soil profile.

Magnesium, sodium, and hydrogen ion changes may be due to alteration in stand structure caused by mortality. The proximity of these stands to the coast increases importance of sea salt aerosols. The ion ratios of chloride, sodium, and magnesium in rain, throughfall, (Blood and others, in press) and even streamflow (Wolaver and Williams, 1986) are similar to sea water ratios indicating movement of essentially unchanged sea salts through the ecosystem. Reduction of both magnesium and sodium in this study suggest that sea salt aerosol impaction was lower in the stand defoliated by beetle attack.

The changes in hydrogen ion concentrations may also be related to aerosol impaction. Hydrogen ion input is primarily as weak sulfuric acid to this forest (Blood and others , in press). In their study sulfate in throughfall and stemflow indicated a substantial contribution of aerosol sulfate, although a direct link of aerosol input of hydrogen ion could not be made. In this study hydrogen ion behaves in the same manner as sodium and magnesium which are linked to aerosols.

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THE EFFECTS OF SILVICULTURAL PRACTICES ON SOIL WATER CHEMISTRY OF SOUTHERN PINE FORESTS[1]

Laurin Wheeler[2]
Timothy T. Ku
Robert J. Colvin

Abstract.--Site preparation and fertilization increased nitrate-N leaching in a loblolly-shortleaf pine stand. Site preparation with burning increased nitrate-N to a maximum of 18 ppm as compared to 5 ppm without. Nitrate in soil water returned to baseline conditions within about one year. Nitrate leaching from fertilization was greater in uneven-aged stands than in even-aged ones. There was no direct effect on leaching from hexazinone application or controlled burning. Hexazinone applied after fertilizer did increase nitrate leaching by reducing its uptake[3].

INTRODUCTION

The silvicultural practices employed in southern pine forests have greatly intensified during the past two decades. During this period, there has been a shift to plantation culture with the use of intensive site preparation, controlled burning to reduce fuel and hardwoods, herbicides to control hardwoods, and fertilizers to correct nutrient problems. There has also been a concern that some practices, such as intensive site preparation or whole tree logging, for example, would deplete the site´s nutrient stocks causing eventual decline in growth rate (Frederiksen and Harr 1979; Kelley and Henderson 1978.) Because of the linkage between forest and surface and ground waters, there has also been a concern that these waters may be degraded by intensive silvicultural practices.

Nitrogen is the element of most concern because it is very mobile and because of a general belief that it is the element that most often limits biomass accumulation (Jurgensen, Larsen and Harvey 1979; Vitousek and others 1979, 1982). This paper examines the movement of nitrogen in the soil-water system in response to the following silvicultural treatments: site preparation, controlled burns, and the use of herbicides and fertilization.

MATERIALS AND METHODS

The study area was located on the University of Arkansas Southwest Research and Extension Center near Hope, in southwestern Arkansas, in an uneven-aged, mixed loblolly-shortleaf pine stand (Pinus taeda, and P. echinata), which had a well developed hardwood understory. The stand had been managed for approximately 30 years, with the last harvest occurring three years prior to the commencement of this study. The soil, a Sacul loam, is a clayey, mixed, thermic Aquic Hapludult developed on coastal plain sediments.

The study consisted of two phases, the first was an area established in 1976, which would be converted to plantation culture, and the second, an uneven-aged component added in 1982. Eight groundwater sampling stations were installed in the even-aged area, and 12 were established in the uneven-aged stand. Two additional stations were established in the uneven-aged stand in 1976 and were to serve as a control. A sampling station in the even-aged and uneven-aged control plots consisted of:

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[2] Associate Professor, University of rkansas, Fayetteville, Arkansas 72701; rofessor, University of Arkansas, onticello, Arkansas 71655 and Research ssistant, University of Arkansas, Hope, rkansas 71801.

[3] We thank Dr. C.E. Walls and the uPont Company for furnishing the Velpar sed in the study.

1-Four soil tubes fitted with a porous ceramic cup installed at depths of 15, 30, 45 and 60cm and

2-Three piezometers installed at depths of 90, 180, and 360cm.

The 15, 30, and 45cm soil tubes were not included in the uneven-aged part of the study because of the infrequency of samples found at these levels during the first phase of the study. The 90 cm piezometer had holes bored at 5 cm intervals between the 60 and 90 cm depths. The 180 and 360 cm piezometers had holes at 15 cm intervals between 90 and 180 cm and between 180 and 360 cm, respectively.

The first leachate samples were collected in January, 1976. Thereafter, samples were collected after each 0.6 cm incident rainfall. The samples collected from the piezometers were taken from all of the water column. A vacuum (ca. 0.6 atm) was drawn on the soil tubes, and the samples were collected the next day. Water depth of piezometers or volume of soil tubes was recorded at the time of sampling. Water samples were preserved with phenylmercuric acetate and refrigerated until they were packed in insulated boxes and shipped to Fayetteville for nitrate analysis. Nitrate-nitrogen was determined by the micro-Kjeldahl steam-distillation method (Bremner, 1965).

The stand designated to receive the site preparation treatments was clear-cut beginning in February, 1978. Harvest was completed in May, at which time the soil tubes and piezometers were removed prior to site preparation. The plots (0.2 ha) received a randomly allocated site preparation consisting of either a minimum (rolling chop) or a maximum (rolling chop, burn, plow) treatment. The plowing in the maximum treatment was done to simulate heavy disking. Site preparation treatments were completed by the end of August. Soil tubes and piezometers were cleaned and reinstalled during September. The area was planted with "improved" loblolly pine seedlings in March, 1979.

Seventy kg N/ha were applied to four even-aged plots in March, 1982 and again in 1983. The first year, two plots received urea and two received ammonium nitrate. The second year the application was switched, and the plots that received urea the first year received ammonium nitrate and vice versa for a total of 140 kg N/ha. Two uneven-aged plots received 230 kg N/ha in April, 1985, and additional paired plots were fertilized in October, 1985 and in April, 1986. In each case, one member of the pair had been burned and the other had not. Paired uneven-aged plots were burned in June and December of 1984, in July 1985, and in January, 1986. Hexazinone was applied as a liquid at a rate of 2.2 kg/ha 25% active ingredient in April, 1986 to two plots that had received the minimum site preparation.

RESULTS AND DISCUSSION

The period after the completion of site preparation was drier than normal. The rainfall for September and October, 1978 was 1.1 and 2.3 cm. The thirty year average for these months was 10.9 and 8.4 cm respectively. During September and October, there was no free water above 180 cm. There were 3 rainfall events in November which totaled 21.8 cm. The second rainfall was 15 cm and was sufficient to produce water samples at all depths.

Background levels of NO_3^--N were typically about 0.5 ppm. There were seasonal peaks, which occurred in winter and were about 1.5 ppm. These small peaks were probably the result of a low rate of nitrification coupled with a reduced uptake and storage, which should occur in winter. These values were somewhat higher than, but consistent with, soil water NO_3^--N levels found in slash pine (P. elliotti) plantations (Burger and Pritchett 1988) or in Southeastern coastal plain loblolly (Williams and Askew 1984).

Nitrate-N in the minimum site preparation treatment increased during November, 1978 to 3 - 5 ppm (depending on depth). The highest value was found at the 15 cm level. The values remained elevated until April, when they began to decline, and they reached background levels in July. The decline in NO_3^--N corresponded to the period of vegetation regrowth in the spring and suggested that the decline in concentration was a result of greater uptake by the vegetation. In general, there was a lag in the above dates with depth, and the time events occurred about one month later at 180 and 360 cm.

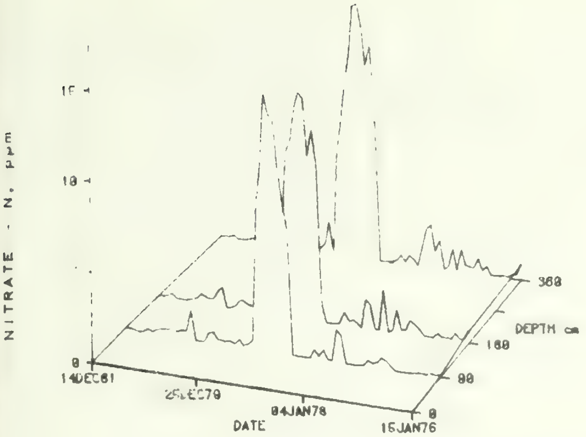

Figure 1.--Nitrate-N in the soil water after site preparation with fire.

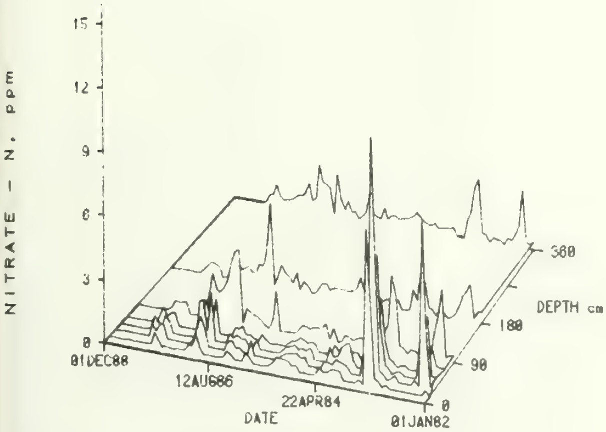

Figure 2.--Nitrate-N in the soil water following fertilizing in even-aged plots.

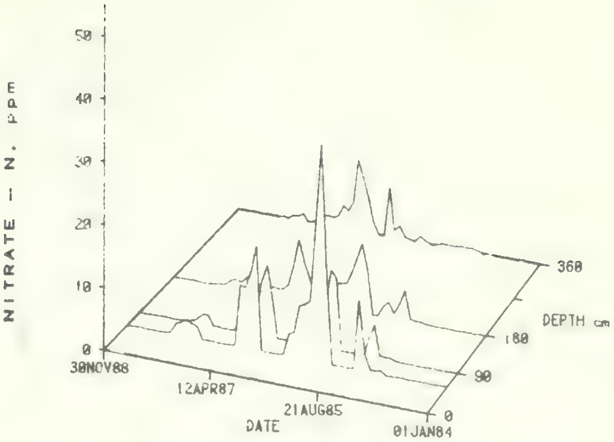

Figure 3.--Nitrate-N in the soil water after fertilizing uneven-aged plots.

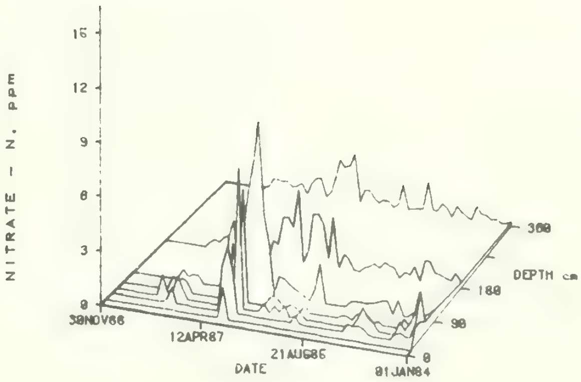

Figure 4.--Nitrate-N in the soil water after hexazinone was applied to a fertilized, even-aged plot.

The loss of NO_3^--N from the maximum site preparation treatment was more dramatic (fig. 1). The leaching began rapidly as in the minimum treatment. Elevated levels of nearly 6 ppm were reached at 90 cm during November. The values below 90 cm lagged by about one month. The highest value of 18 ppm was reached in January at the 15 cm depth. A maximum value of 15 ppm occurred during March in the 360 cm piezometers. Background levels were reached by July to a depth of 90 cm and in September in the 360 piezometers. The decline in NO_3^--N in the soil water to a depth of 90 cm coincided with the disappearance of free water from that zone and indicated that vegetation dynamics and uptake are critical factors in preventing N losses from forests as found by Marks and Bormann (1972) and by McLaughlin, Pope and Hansen (1985).

There was immediate leaching of N from both applications of fertilizer in the even-aged plots (Fig. 2). The second application led to a maximum value of 10 ppm at 30 cm. The source of NO_3^--N appears to be directly related to the vegetation's inability to absorb the fertilizer when applied. Nitrate quickly returned to baseline conditions, within one or two months, after application. There was no detectable differences in NO_3^--N levels between urea or ammonium nitrate fertilizers or between site preparation treatments.

Fertilizing the uneven-aged stand led to more persistent and greater concentrations of NO_3^--N in the soil water. As in the even-aged stand, there was an initial peak that was related to the fertilizer being flushed through the system before it could be incorporated (fig. 3). Although the NO_3^--N values in the uneven-aged were higher than in the even-aged stand (figs. 2 and 3), the major difference was in the behavior of nitrification in the uneven-aged stand. Nitrification occurred in all plots at least one growing season after fertilizer application and in some plots three years after application. Nitrate levels generally increased in January, one or two months after free water returned to the soil. This suggests that the rate of nitrification (and perhaps mineralization) increased in mid-winter at a time when uptake was low, resulting in greater leaching.

Hexazinone was applied to only two plots, one which was also fertilized and one which was not. Nitrate-N increased in the ground water in the fertilized plot in the fall after hexazinone was applied (fig. 4) but not in the unfertilized plot. The timing of the NO_3^--N increase in this work is identical to that found by Vitousek and Matson (1984) in the North Carolina Piedmont, and the maximum concentration of 10 ppm is comparable to the maximum value they found of about 8 ppm. The release of NO_3^--N was unquestionably a function of the decay of vegetation, the release of nitrate, and the stand´s inability to store the nitrate in biomass.

We had anticipated that the large amount of leaf litter in the uneven-aged stands would have lead to immobilization of N. If this had been true, there should have been significant differences in nitrate in the groundwater between burned and unburned plots that had been fertilized. However, this was not the case. There was no detectable difference between them.

CONCLUSIONS

Both levels of site preparation increased the loss of nitrogen from the sites. However, the loss was much greater when fire was also used. Given the ease with which nitrogen was lost from the system, nitrogen does not appear to be a limiting element. The loss of nitrogen caused by site preparation does not appear to be important.

Nitrogen loss to the ground water from fertilization and herbicide application are directly related to biomass accumulation.

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LONG-TERM BENEFIT OF LESPEDEZA ON LOBLOLLY PINE GROWTH[1]

M.M. Schoeneberger and J.R. Jorgensen[2]

Abstract.--A study to assess the long-term effects of lespedeza, on tree growth was established in 1976 in a one-year old loblolly pine stand located in the North Carolina coastal plain. Treatments included: control (C), 89 kg P/ha (P), sericea lespedeza (S), sericea lespedeza plus P (SP), 168 kg N/ha as urea (U), and urea plus P (UP). Throughout the duration of this study (1976-1987), P-fertilized plots had greater tree volumes than non P-fertilized plots. After 4 years from planting (1979), the largest vol/ha was in the SP treatment. Response to urea was rapid resulting in UP plots having the largest vol/ha one year after application. This trend held until 1982-1983 when SP tree volumes exceeded all other treatment values. Nutrient analysis indicates that the benefit from the SP treatment is due to enhanced nitrogen availability.

INTRODUCTION

The rising costs and fluctuating availability of commercial N fertilizers in the early 1970's prompted a renewed interest in developing biological nitrogen fixing (BNF) systems for forest use. Investigations centered predominantly on the use of leguminous plant-nitrogen fixing (LNF) systems, particularly in the Southeastern United States. The additional benefits LNF systems had the potential to provide (i.e. weed and erosion control, enhancement of wildlife habitat, and organic matter addition) augmented this interest. Many of the LNF systems, which had originally been developed for growth in the higher fertility and lower acidity of agricultural soils, failed when introduced into forest soils (Jorgensen and Craig 1983, Miller and Zalunardo, 1979). Subsequent selection of plant varieties and rhizobia isolates better adapted to the low P, acid conditions generally encountered in forest soils resulted in improved establishment (Jorgensen and Craig 1983, Thornton and Davey 1983). Fertilization with P was also found to improve LNF establishment and persistence (Jorgensen and Craig 1983).

Despite these advances, use of LNF systems in forest operations is still not viewed as a routine silvicultural option to increase tree growth. This is due to 1) current low costs of N fertilization, 2) recent advances in our understanding of stand response to commercial fertilizers (NCSFNC 1988), and 3) insufficient information on the management of LNF systems as routine forest operations with which to properly evaluate their effects on forest production. Thus, use of commercial N fertilizers remains the economic choice at this time.

Research on the use of LNF systems, however, should not be abandoned. Gordon (1984) points out that both "the low gas prices as well as overcapacity can not be expected to persist a long time relative to forest production cycles" and that given a future scarcity of commercially-produced N fertilizers, allocation will be for food production rather than forest use. Growing environmental concerns on water pollution from forest fertilization provide further impetus for continued research into the use of the LNF system.

Evaluation of the long-term effects of LNF systems on tree growth based on a short time period is difficult due to the initial competition between the tree and LNF system for limited resources (i.e. light, water and nutrients), and to a lag between the time N is fixed by the system and is available to the trees. Thus, the effects of LNF systems on tree growth may be neutral or even negative initially. Any other additional benefits afforded by the LNF system may also not be readily evident and thus difficult to assess with regards to longer-term forest production.

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[1] Paper presented at the Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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In the South various species of lespedezas have been found to be well-suited to the generally adverse soil conditions of forests and to the low degree of site preparation used in forest operations. However, the ability for rapid, highly competitive growth under these conditions has given some lespedezas a reputation for inhibiting the establishment and growth of planted pines. Common sericea (Lespedeza cuneata (Dumont) G. Don) has an especially bad reputation for hindering seedling survival and early growth (Jorgensen 1984, Nix 1984, Van Sambeek et al. 1986). Other studies (Bengtson and Mays 1984, Vogel, 1973) found that after an initial period of suppression, sericea enhanced tree growth: this benefit not becoming evident until after the fourth to the sixth growing season.

Some lespedeza-pine competition, in situations where both plants are desirable, has the potential to be modified by the selection of improved varieties or different species of lespedezas, and by modifications in lespedeza seeding and pine planting practices. Wide spacing between rows would reduce the initial competition between the leguminous plant and pine and also afford the leguminous plant more time to grow before being shaded out by trees. Seeding the leguminous plant a year or more after tree establishment may also reduce competition.

OBJECTIVES

The objectives of this study were to measure the influence of lespedeza and P fertilization on long-term loblolly pine (Pinus taeda L.) nutrition and growth, and to compare long-term tree response to "biological fertilization" via lespedezas with that of a commercial N fertilizer (urea). Both wide spacing and delayed introduction of lespedeza were utilized as management options in this study to optimize potential benefit from the LNF system.

METHODS

Site Description

The study site was located on the Coastal Plain in the Croatan National Forest just south of New Bern, North Carolina. The soil type was a sandy loam (Goldsboro series: fine-loamy, siliceous, thermic Aquic Paleudult). The soil, analyzed immediately after P fertilization in 1976, was found to have the following chemical composition: pH 4.1; total N, 0.06%; and double-acid extractable P, 3.0 and 6.8 mg/kg for soil not P-fertilized and P-fertilized, respectively. The site index was 90 feet (27 m) at age 50. The site had been drum-chopped and windrowed prior to being planted in the spring of 1975 with one year-old loblolly pine seedlings. Spacing was approximately 4 meters between rows and 2 meters between trees within rows.

Treatments and Plot Layout

Plots were established in spring of 1976 and treatments assigned in a randomized design allowing 3 replications per treatment plus two additional plots per replication for check treatments. Each plot was 0.09 ha (30m x 30m) and contained approximately 111 trees. Inner measurement plots (0.024 ha) were established which contained approximately 30 trees. Treatments were as follows: control (C), common sericea lespedeza (Lespedeza cuneata (Dumont) G. Don) (S), 'Caricea' lespedeza - an improved variety of common sericea (L), Thunbergii lespedeza (L. thunbergii (D.C.) Nakai) (J), 168 kg N ha^{-1} applied as urea in May 1980 (U). Ground rock phosphate was applied at the time of lespedeza seeding to one half of the plots at a rate of 89 kg P ha^{-1} resulting in the following treatments: P-alone (P); lespedezas plus P (SP), (LP), and (JP); and urea plus P (UP). The lespedeza seeds were treated with the appropriate rhizobia inoculum and broadcast sown on recently disked strips between tree rows.

Study Measurements

Tree heights were measured each year starting in the fall of 1976 and in late winter (February-March) for each year thereafter until 1985 and again in 1988. When trees became tall enough, DBH (diameter at breast height) was also recorded. Stemwood volume growth was calculated from these measurements using the equation of Smalley and Bower (1968). The most current needles (representing the prior year's status) were also sampled at this time and analyzed for nutrient level. Analysis of variance procedures were used to test treatment differences. Treatment means were compared using Duncan's new multiple range test at the 10 percent level.

RESULTS AND DISCUSSION

Lespedeza Establishment

All three lespedezas became established at the site; the early production of the sericeas (common sericea and 'Caricea') being greater than that of Thunbergii lespedeza. Lespedezas sown on non P-fertilized plots, however, produced little biomass and did not persist to any great extent beyond the fourth treatment season. Biomass production of the two sericeas on P-fertilized plots (SP and LP) declined sharply after the sixth treatment season (treeage: 8 yr); a result most likely due to increased shading from stand closure. To date (6/88), Thunbergii lespedeza in P-fertilized plots (JP) has continued to persist.

Table 1.--Height of loblolly pine by year and cultural treatment

YEAR		1980	1981	1982	1983	1984	1987
Yrs. since lesp. establishment		(4)	(5)	(6)	(7)	(8)	(11)
Treatment	ID	(m)					
Control	(C)	5.02	6.35	7.63	9.25	9.9	12.54
Urea-only	(U)	5.09	6.28	7.28	8.00	9.35	11.90
Sericea-only	(S)	5.08	6.46	7.98	9.40	10.21	12.62
P-only	(P)	5.24	6.63	8.09	9.09	10.35	13.67
Urea+P	(UP)	5.65	6.88	8.72	9.97	10.68	13.83
Sericea+P	(SP)	5.50	6.92	8.39	10.13	10.89	13.92
Main Effect of P-Fertilization[1]							
(C, U and S)		5.04	6.36	7.66	9.09	9.92	12.44
(P, UP and SP)		5.46	6.81	8.40	9.73	10.64	13.81

[1] P-fertilized versus non P-fertilized treatments differ significantly (P<005) for all years.

Pine Growth

Presentation of results in this paper will be concentrated on effects produced by common sericea (S) and to the post-urea application period (1980 - 1987). Results on the other treatments for the early time period have been presented elsewhere (Jorgensen 1980, Jorgensen and Craig 1984).

Although P-fertilization did not provide an immediate tree growth response in the first three seasons after P application (Jorgensen 1980), tree heights from 1980 to 1987 were significantly greater in P plots than non-P plots (table 1). Urea added to non-P plots produced no additional growth: a result most likely due to a P-deficiency. Both non P-fertilized soil (3 mg kg^{-1}) and control treatment foliar (0.10%) P levels were at the critical levels (Wells et al. 1973). Response to urea in the presence of P was rapid, as expected, with urea plus P trees having significantly greater heights and diameters than P-only trees by the end of the first year after application (unpublished data). Stemwood volumes of both "N-fertilized" plus P plots (UP and SP) were significantly greater than control (C) or P-only (P) plots at this time(1980) (tables 2). From 1980 to 1982, UP plots continued to have the greatest tree volumes. These values were significantly different from C the greatest tree volumes. These values were significantly different from C and P plots, but not significantly different from SP plots. From 1983 to 1987, this trend reversed itself with SP plots having the greatest tree volumes. Values for SP plots were always significantly greater

Table 2.--Mean stemwood volume of loblolly pine by year and cultural treatment

YEAR		1980	1981	1982	1983	1984	1987
Yrs. since lesp. establishment		(4)	(5)	(6)	(7)	(8)	(11)
Treatment	I	(m^3 tree^{-1})					
Control	(C)	0.012b	0.023c	0.038c	0.058b	0.081c	0.135b
P-only	(P)	0.014b	0.026bc	0.041bc	0.060b	0.085bc	0.168ab
Urea+P	(UP)	0.019a	0.032a	0.057a	0.073a	0.097ab	0.176ab
Sericea+P	(SP)	0.016a	0.031ab	0.050ab	0.075a	0.102a	0.187a

Means within a column followed by the same letter do not differ significantly differ (P<0.10).

Table 3.--Mean nitrogen and phosphorus concentrations in loblolly pine needles by year and treatment

YEAR Yrs. since lesp. establishment		1978 (2)		1981 (5)		1984 (8)	
Treatment	ID	N	P	N	P	N	P
		(percent)					
Control	(C)	1.43	0.10	1.34	0.10	--[1]	--
P-only	(P)	1.47	0.12	1.28	0.12	1.12	0.10
Sericea	(S)	1.47	0.07	1.40	0.10	--	--
Sericea+P	(SP)	1.51	0.12	1.43	0.11	1.21	0.10
Urea+P	(UP)	1.43	0.12	1.42	0.12	1.10	0.10

[1] Data not available

than values for C plots, were significantly greater than P-only (P) plots in1983 and 1984 but not 1987, and were not significantly different than UP plots. In all the years, tree growth on sericea (S and SP) plots was equal to that of control (C) plots, indicating that sericea did not have a negative influence on the growth of pine at any time during this period.

Pine Nutrition

Trees on the SP plots consistently had the highest foliar N concentrations (table 3). While foliar N levels for the other treatments initially were never below the critical level of 1.2% (1978 and 1981), foliar levels for 1984 indicate N may have become limiting for P-only plots (P) and urea plus P (UP) plots. Nitrogen concentrations in the sericea plus P (SP) plots were still above the critical level at this time. The foliar analysis, along with the soil and understory biomass N analyses presented by Jorgensen (1980) suggests the tree response to sericea in the presence of P, is due to enhanced nitrogen availability. Whether or how much the enhanced growth and elevated N status of the trees is due to biological fixation can not be determined from this study. Data from Moser (1985) showed that sericeamay have also benefited pine growth by controlling understory competition; such a benefit would be confounded with that derived from biological fixation.

Management Implications

Growth data showed that the general trend for the treatment of sericea plus P did enhance pine growth. The benefit from sericea plus P overthat of P-fertilization alone, however, was not always significant. By 1987, the sericea plus P treatment only showed a small nonsignificant increase over that of P-fertilization. The stands at this stage have been closed for some time and are in need of thinning. The incidence of fusiform rust has also added to the variability currently observed in these plots.

Tree response to urea in the presence of P was rapid as expected being significantly greater than P-only plots through 1983. This response did not persist. By 1987 there was little difference between P-only and UP treatments. Tree growth on the two N-fertilized plus P plots (UP and SP) were never significantly different, although volumes were greater on the sericea plots from 1983 on. This would suggest the small but continuous N-input via the LNF system may be of greater value to tree growth than a one-shot application of industrially-fixed N fertilizer. Additional information is needed to properly assess this growth enhancement due to LNF.

Evaluation of the benefit of the LNF system in this study needs to include not only that of growth enhancement at this point but also the other benefits derived from it (i.e. wildlife habitat enhancement) and the potential benefits that may be derived from the systems further into the rotation. The persistence of Thunbergii lesedeza may, in particular, provide additional benefit as each thinning allows the LNF system to further reestablish. The persistence of Thunbergii lespedeza in this study indicates it's shade tolerance is greater than that of the other two sericeas used in this study. While pine growth is currently similar on all lespedeza plots (table 4), it would be instructive to look at continued tree performance after thinning. The continued persistence of Thunbergii lespedeza may have enabled continued N-fixation which should further increase once the canopy is opened again. How much and how fast this N would be available for tree growth is not known.

While the ease and economics of industrially-fixed N-fertilization makes it the more attractive choice to increase tree growth at this time, work should continue on the future use of LNF systems. This work will need to include long-term evaluation of the effects of such systems on not only tree growth but on the other potential benefits that may be derived from the system.

Table 4.--Mean height, diameter and stemwood volume of 13-year-old loblolly pine 11 years after lespedeza establishment[1]

Lespedeza	Treatment	Height	Diameter	Volume
		(m)	(cm)	(m^3 tree^{-1})
Sericea	(SP)	13.92	18.30	0.19
'Caricea'	(LP)	13.96	18.32	0.19
Thunbergii	(JP)	13.67	17.88	0.17

[1] Included 89 kg/ha P as ground rock phosphate applied at the time of establishment

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WAX MYRTLE IN A COASTAL PLAIN LOBLOLLY PINE STAND[1]

Carl L. Lane and Jean L. Askew[2]

Abstract.--Wax myrtle growing in a loblolly pine plantation fertilized with triple super phosphate produced a biomass of 31,464 kg/ha and a foliar nitrogen content of 320 kg/ha in three years. Part of the same stand that was not fertilized produced a biomass of 86.4 kg/ha and a foliar nitrogen content of 0.76 kg/ha in the same period. Even with the dense wax myrtle competition, the fertilized pines grew 14.3 meters in height and 18 cm in DBH while the non-fertilized pines grew 8.4 meters in height and 11 cm in DBH during the 11 years of the study[3].

INTRODUCTION

One of the more common plants growing in the understory in the Southern Coastal Plain is wax myrtle (Myrica cerifera L.). Wax myrtle is an evergreen, dioecious, low colonial rhizomatous, much branched shrub or small tree sometime reaching up to 14 meters high (Baird 1968). It is a member of the actinorhizal group of nitrogen-fixing woody plants. Its range extends from southern New Jersey along the Coastal Plain to East Texas and south into Mexico. It does not grow on extremely wet or extremely dry sites nor on very nutrient deficient sites.

Much of the land in the Coastal Plain in relatively deficient of phosphorus, and commercial forest products companies like WESTVACO fertilize many acres each year at planting time. On some of the most phosphorus deficient sites, fertilization makes the difference between growing a crop of trees and not having a commercial crop at all. A helicopter is commonly used to apply the phosphorus, along with any other material that may be used.

WESTVACO had color infra-red satellite images made of some of their phosphorus treated areas and a number of red streaks showed up. Ground observation indicated that the possible cause of the streaks was that the helicopter had missed small linear areas. The red streaks turned out to be areas that had good loblolly pine growth and very dense wax myrtle in the understory. The dark streaks had very poor pine growth and almost no wax myrtle growing on them. The satellite images were made three years after planting.

MATERIALS AND METHODS

A series of studies were started, primarily in the areas with the wax myrtle, to determine the nitrogen status and effects. The first study was to look at nitrogen fixation and biomass production on the fertilized versus some unfertilized areas. The second study was to determine the yearly litterfall, forest floor, soil nutrient status and soil water table status at 50 and 100 cm below the soil surface. The third study was to see if there was any difference in nitrogen fixation between the male and female wax myrtle. The fourth study determined the nutrient status of the myrtle foliage each month for a year.

After these studies were completed, a series of plots were established on the same area. Four replications of the following treatments were applied.

I. Chop wax myrtle and leave it on the ground.
II. Burn the wax myrtle.
III. Basal spray with herbicide on stumps.
IV. Control, leave wax myrtle intact.
V. Completely remove wax myrtle from plots and spray herbicide on stumps.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] Funding for the initiation of this study was provided by WESTVACO. They also provided the research site and some technical assistance. The latter part of the study was funded by McIntire-Stennis funds.

VI. Add cut wax myrtle to pine plots on the missed areas that had no wax myrtle growing.

VII. Pine in area without wax myrtle (control).

Pine height and diameter measurements were made. A new set of tubes was put in to follow the nitrogen status of the water table at 50 and 100 cm.

RESULTS AND DISCUSSION

Foliage and soil nitrogen was sampled from the wax myrtle and away from the wax myrtle to look at nitrogen distribution. Table 1 shows there is a greater soil nitrogen content in the young, fertilized area, and a slightly greater percent of foliage nitrogen in the older stand. Biomass samples were taken from these areas to show the very significant contrast in growth between the areas (table 2). Root nodules were taken and fixation measured using the acetylene reduction technique (Fessenden et al. 1973). Table 3 shows the significant differences between the young fertilized stand, the older stand, and the unfertilized areas. There was no difference in nitrogen fixation between male and female plants.

For a one year period, 10 one-square-meter litter traps were put in the fertilized stand. Monthly samples were taken from the litter traps and from the forest floor adjacent to the litter traps. Table 4 shows the monthly data and the yearly total contribution of the wax myrtle to forest floor. Table 5 shows the great variability in the forest floor weights. This would be expected at this age with the large amount of understory vegetation still in the stand.

The nitrogen distribution in fresh foliage, litter trap foliage, forest floor, soil and ground water is shown in table 6. Although there is considerable nitrogen in the foliage, and sometimes in the soil, the ground water never showed levels approaching established minimums for potential nitrogen pollution.

The dried litter trap foliage nutrients shown in table 7 indicate the contribution of the litterfall to the potential available in the soil, while table 8 shows that most of the foliage nitrogen is not translocated from the foliage prior to litterfall, but that more than half of the P and K are moved to other parts of the plant prior to leaffall.

In the treatments imposed on the stand, the heights and DBH's were as follows after five years of treatment (11 years of age):

Treatment	Height	DBH
Fertilized		
	Meters	Cm
Chop wax myrtle	12.7	17.8
Burn	13.7	18.5
Basal spray	12.3	18.0
Control	13.5	17.5
Remove was myrtle	13.7	19.0
200 lbs/A NO_3/A	13.4	19.0
Unfertilized		
Control	8.2	11.4
Add cut wax myrtle	9.7	13.7

As can be seen, in the fertilized area, the main difference is the basal spray which was carried to the pine during a hard rain after treatment. This caused a one year height growth loss. Carrying the wax myrtle from the fertilized area to the unfertilized area caused a significant increase in both height and diameter growth during the five years of the study period. The stand was 11 years old at the time of measurement.

CONCLUSIONS

As has been known for many years, fertilizing phosphorous deficient stands causes a significant increase in pine growth. It also seems to cause a significant increase in wax myrtle growth as well. These wax myrtle fix a large amount of nitrogen in their foliage. It is probable that soils with relatively good wax myrtle growth do not need phosphorous fertilization. It is also likely that the current practice of using prescribed fire in these pine stands at around 10-12 years of age is most practical as a method of getting the nitrogen and other nutrients that are in the wax myrtle foliage into the soil where the pines will have ready access to it.

Table 1.--Foliage N and soil N beneath (A) and away (B) from the crown of wax myrtle in loblolly pine stands

Foliage N (%)	Site	Kg/ha A	Kg/ha B
1.87	3-year-old pine Plantation	19.5	15.2
2.14	30-year-old pine Plantation	4	4

Table 2.--Biomass content in 3-year-old fertilized, unfertilized, and 12-year-old wax myrtle in loblolly pine stands

	Kg				
	Roots	Nodules	Stems	Foliage	Total
Per tree[1] fertilized	1.447	0.018	2.925	0.854	5.244
Per ha[2] fully stocked	8671	107.4	17550	5122	31464
Per tree[3] unfertilized	0.070	0.0009	0.108	0.037	0.216
Per ha[4] fully stocked	28.1	0.375	43	14.9	86.4
Per tree[5] 12-yr old	3.025	0.001	8.994	0.222	12.243
Per ha[6]	12102	4.04	35980	888	48972

[1] Means of 18 trees

[2] 6000 plants/ha

[3] Means of 75 trees

[4] 400 plants/ha

[5] Means of 8 trees

[6] 4000 trees/ha

Table 3.--Acetylene reduction and biomass N content for wax myrtle in three loblolly pine stands

3-yr-old		12-yr-old
Fertilized	Unfertilized	
	Kg N fixed/ha/150 days	
32.4	0.113	1.33
Biomass N content (kg/ha) at sampling time		
320[1]	0.76[2]	415[3]

/ 6000 trees/ha

/ 400 trees/ha

/ 4000 trees/ha

Table 4.--Monthly wax myrtle litterfall in a 3-to 4-year old fertilized loblolly pine plantation (kg/ha)

Date	Mean	Date	Mean
5-81	738	11-81	265
6-81	283	12-81	110
7-81	204	1-82	92
8-81	181	2-82	142
9-81	183	3-82	145
10-81	724	4-82	82

Total = 3149

Table 5.--Monthly forest floor weights in a 3-4-year-old fertilized loblolly pine plantation with dense wax myrtle (kg/ha)

Date	Mean	Date	Mean
5-81	16307	11-81	27243
6-81	21323	12-81	13056
7-81	12636	1-82	19590
8-81	20236	2-82	16468
9-81	20235	3082	15780
10-81	15521	4-82	12712

Table 6. Nitrogen content in (1) fresh wax myrtle foliage, (2) litter trap wax myrtle foliage, (3) forest floor, (4) soil, (5) and groundwater

	% N			ppm N	
Date	Fresh foliage	Litter trap	Forest floor	Soil	Ground-water
10-81	1.39	0.83	1.26	7.0	-
11-81	1.59	0.91	1.25	8.3	-
12-81	1.43	0.94	1.06	4.1	2.37
1-82	1.48	1.13	1.32	16.8	0.54
2-82	1.27	1.25	1.27	4.0	0.25
3-82	1.50	1.11	1.23	46.6	0.39
4-82	1.52	1.14	1.14	5.3	0.33
5-82	1.71	1.17	1.37	12.5	0.42
6-82	2.03	1.13	1.34	9.6	-

Table 7.--Litter trap wax myrtle foliage nutrients (kg/ha)

Date	N	P	Ca	Mg	K
7-81	2.97	0.057	3.65	0.54	0.14
8-81	1.79	0.041	2.20	0.37	0.14
9-81	1.74	0.018	2.08	0.36	0.08
10-81	1.63	0.018	2.34	0.42	0.16
11-81	6.59	0.072	7.46	1.38	0.29
12-81	2.99	0.053	3.37	0.61	0.13
1-82	1.24	0.033	1.18	0.22	0.05
2-82	1.15	0.028	0.90	0.18	0.09
3-82	1.58	0.028	1.43	0.27	0.08
4-82	1.68	0.029	1.65	0.29	0.12
5-82	0.97	0.016	1.07	0.18	0.06
6-82	8.78	0.078	11.11	1.71	0.31
	33.11	0.471	38.44	6.53	1.65

Table 8.--Mobility of nutrients from wax myrtle % of fresh foliage nutrients in litter trap foliage

Date	N	P	K
7-81	60.2	30.6	15.8
8-81	66.7	66.7	26.3
9-81	65.6	45.1	37.4
10-81	64.0	25.0	47.4
11-81	57.2	20.0	25.0
12-81	79.0	50.0	26.3
1-82	75.8	60.0	29.4
2-82	98.4	75.0	62.5
3-82	74.0	40.0	31.6
4-82	76.3	40.0	36.4
5-82	69.0	33.3	25.0
6-82	55.7	12.5	10.0
$\bar{X}$	70.2	41.5	31.5

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Soil-Site-Stand Relations

Moderator:

Nelson S. Loftus

USDA Forest Service

EVALUATION OF FOUR SOIL-SITE INDEX ESTIMATORS FOR LOBLOLLY PINE IN THE WEST GULF REGION[1/]

James M. Guldin, James B. Baker, and Brian R. Lockhart[2/]

Abstract.--Four soil-site evaluation methods that estimate the site index of loblolly pine (Pinus taeda L.) were tested for accuracy across a range of sites in southern Arkansas. Site index was measured on each plot using tree height-age methodology. Estimates of site index for each of 51 plots were made using (1) Zahner's field procedure, (2) Zahner's regression procedure, (3) Baker-Broadfoot's field procedure for sweetgum (Liquidambar styraciflua L.), and (4) a modification of the Baker-Broadfoot sweetgum field procedure for loblolly pine. The order of highest to lowest correlation between each method and measured site index was the unmodified Baker-Broadfoot method > modified Baker-Broadfoot method > Zahner field method > Zahner regression method. The most accurate method was the modified Baker-Broadfoot method, which estimated site index within ±10 feet of measured site index 9 times in 10.[3/]

INTRODUCTION

Site index, the average total height of dominant and codominant trees in well-stocked stands at a specified index age (Avery 1975), is the most common method of expressing the quality of a forested site. For even-aged stands near the base age, site index is relatively easy to assess. It is a much less reliable estimator in uneven-aged stands and in mismanaged stands, because of the possibility that the dominant and codominant stems may have undergone a period of suppressed growth. Also, site index cannot be measured directly on a site devoid of trees, such as pasture or agricultural land.

One approach to consider in non-traditional situations is to estimate site index from soil parameters. Using this concept, a forester could estimate the productivity of sites without suitable index trees. This would provide landowners with better advice on the feasibility of applying different silvicultural alternatives on a given site.

The objective of this study was to evaluate several existing soil-site evaluation methods for estimating the site index of loblolly pine (Pinus taeda L.) in the West Gulf Region of the southern Coastal Plain.

PROCEDURES

Three methods that use soil-site parameters to estimate site index are applicable to loblolly pine in the West Gulf Region. The first is a field procedure developed by Zahner (1957). In this method, soils are first categorized as "zonal" or "azonal". Zahner defined zonal soils as having pronounced horizon development; azonal soils had a low degree of horizon development as judged using a soil auger. Site index for azonal soils was estimated using slope percent and field texture classification of both subsoil and surface soil. On zonal soils, site index was estimated using slope percent, surface soil thickness, and field texture classification of the subsoil. Site index prediction tables were produced using various combinations of these variables.

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Another method is a laboratory-based regression technique, also developed by Zahner (1958). In this method, the zonal/azonal categorization is required, and regression equations to predict site index were developed utilizing the following variables. For zonal soils, regression equations were based on percent clay in subsoil, thickness of surface soil, and percent slope. For azonal soils, equations were based on percent sand at a depth of 24", percent silt at a depth of 6", and percent slope.

Zahner's azonal soils probably included entisols and some alfisols; his zonal soils probably included alfisols, inceptisols, and ultisols. When using Zahner's methods, sites located on bottomland fluvial soils were assigned a site index value of 95 as recommended by Zahner (1957, 1958), since his tables were not intended for bottomland soils.

The third method is a field procedure for sweetgum (Liquidambar styraciflua L.), developed by Baker and Broadfoot (1979). This method was included because of the ecological similarities between sweetgum and loblolly pine. Published site indices for the two species are often similar over a wide range of soil series (USDA 1979). Also, workers have noticed similarities in growth rates between the species (Kellison et al. 1976).

The Baker-Broadfoot method for sweetgum contains a strong deduction for the presence of a fragipan in the soil. The roots of sweetgum cannot easily penetrate a fragipan, and this reduces the productivity of sites with fragipans for the species. However, loblolly pine is a taprooted species, and it is hypothesized that this habit allows the presence of a fragipan to be less ecologically limiting in loblolly pine than in sweetgum. Therefore, a modification of the sweetgum site evaluation method was devised in which no deduction was made for the presence of fragipan layers. Both the original Baker-Broadfoot method and the modified method were tested in this study.

METHODS

The sample plots for this study were drawn from a 228-plot data base established by Ku et al. (1980) as the uninfested control plots during a recent study of the southern pine beetle. These plots were located, with few exceptions, five chains to the northeast of the intersection of each township and range corner in the southern part of the state. For this study, all plots with less than 60 square feet of basal area in pine were rejected, as were any plots with more than 40 percent of the basal area in hardwood stems or more than 50 percent of the pine basal area in pine species other than loblolly pine. The 111 plots which passed this preliminary screening were ordered using random numbers. The first seventy-five plots were visited; of these, 51 plots were selected and included in the study (fig. 1).

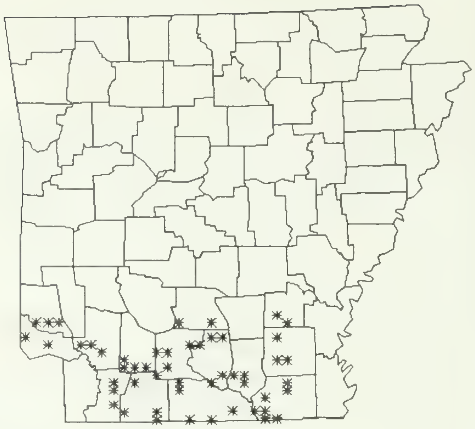

Figure 1.--Approximate location of 51 sample plots in this study.

At each plot, total height of two dominant or strongly codominant pines was recorded. An increment core from each tree was taken at 4.5 feet for laboratory age determination. It was initially hoped that these two trees would provide confirmation of site index determination taken through stem analysis from the previous study. Unfortunately, it was not possible to confirm that the stands visited in this study were identical to those in the previous study; as such, no historical data were utilized in this study. Measured site index in this study was therefore based on the two-tree samples.

A small soil pit was dug at or near the plot center at a spot devoid of microtopographic or edaphic irregularities, to determine soil conditions for the Baker-Broadfoot methods and to assess the extent of horizon development for the methods of Zahner. Measurement of pH was done in the field using a Hellige-Truogg field pH kit. Surface and subsurface soil samples were taken from each of three faces of the soil pit, and combined for the laboratory analyses required in one of Zahner's methods.

In the lab, tree rings were counted using a binocular microscope. The total age of each tree was determined by adding 3 years to each increment core, and site index (at base age 50) was derived for each tree using standard height-age relationships (USDA 1929, Farrar 1973). The measured site index for each sample plot was obtained by averaging the two site index values on that plot.

Laboratory texture analyses were performed using the Bouyoucos hydrometer method (Day 1965). Four estimates of site index were then obtained for each plot by applying the site evaluation procedures of the two Zahner methods and the two Baker-Broadfoot methods. Each estimate was then compared to measured site index values using correlation and first-order linear regression methods. Accuracy of each of the site evaluation methods was assessed using a modified Chi-square test (Freese 1960).

RESULTS

The distribution of measured site index values, and the tree ages from which those values are derived, are presented in Table 1. Site index values ranged from 63 to 105 feet, with the majority of plots falling in the range of 80 to 89 feet. The ages of the stands in which plots were located varied from 20 to 79, with most falling between 30 and 49.

Scatterplots of measured site index versus the unmodified Baker-Broadfoot, the modified Baker-Broadfoot, the Zahner regression, and the Zahner field site evaluation methods are presented in Figures 2 through 5, respectively. The largest observed differences between estimations and measured site index were underestimates of measured site index by the estimation methods; the Zahner methods show both a broader degree and a more consistent pattern of underestimation of measured site index than the Baker-Broadfoot methods.

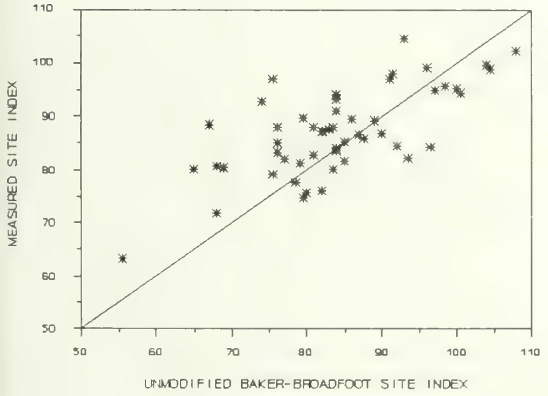

Figure 2.--Measured site index versus the unmodified Baker-Broadfoot site evaluation for 51 study plots.

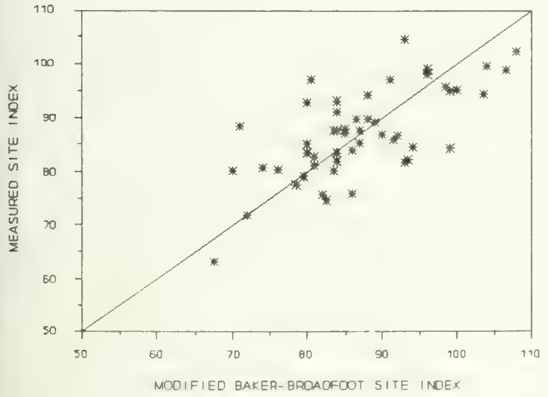

Figure 3.--Measured site index versus the modified Baker-Broadfoot site evaluation for 51 study plots.

Table 1.--Distribution of tree ages and measured site indices for plots in this study

A. Tree ages, years

	20-29	30-39	40-49	50-59	60-69	70-79	TOTAL
# of Trees	20	51	25	1	4	1	102

B. Measured site index, feet at age 50

	<70	70-79	80-89	90-99	>100	TOTAL
# of Plots	1	6	27	14	3	51

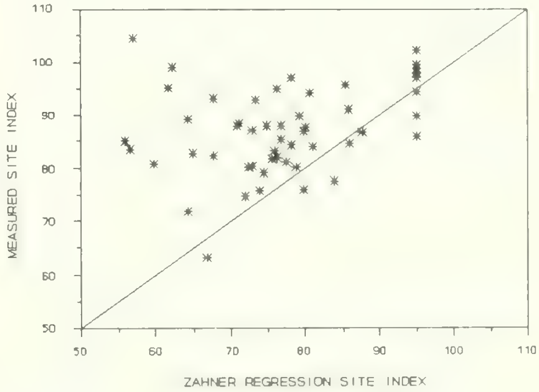

Figure 4.--Measured site index versus the Zahner regression site evaluation for 51 study plots.

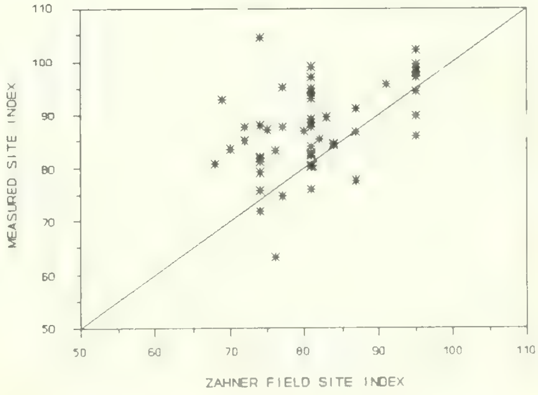

Figure 5.--Measured site index versus the Zahner field site evaluation for 51 study plots.

Results of the correlation analyses are presented in Table 2. Of the four methods, the order of highest to lowest correlation with measured site index is the unmodified Baker-Broadfoot method > modified Baker-Broadfoot method > Zahner field method > Zahner regression method. All of these correlations are significant at the 5% level; the first two are significant at the 0.1% level, the third at the 1% level (Snedecor and Cochran 1967). The highly significant correlations between the two Baker-Broadfoot methods and the two Zahner methods indicate the similarity with which each of these classify site index, and are not unexpected.

Results from linear regression analyses are presented in Table 3. The Baker-Broadfoot methods and the Zahner field method are superior to the Zahner regression method, as judged by the F-test for significance of regression.

The results of the modified Chi-square test for accuracy (Freese 1960) are presented in Table 4. These tests indicate that either Baker-Broadfoot method will estimate measured site index within ±15 feet 95 times out of 100. The best estimates are provided by the modified Baker-Broadfoot method, which predicts within ±10 feet of measured site index nine times in ten. At the nine-of-ten level of confidence, accuracy to within ±15 feet of measured site index could be obtained by both Baker-Broadfoot methods and by the field method of Zahner.

Table 2.--Correlation coefficients between measured site index (SI) and four site evaluation methods:

UBB, unmodified Baker-Broadfoot method;
MBB, modified Baker-Broadfoot method;
ZR, Zahner Regression method;
ZF, Zahner Field method

	SI	UBB	MBB	ZR
UBB	0.696^{***}	-----	-----	-----
MBB	0.684^{***}	0.972^{***}	-----	-----
ZR	0.311^{*}	0.375^{**}	0.452^{***}	-----
ZF	0.457^{**}	0.515^{**}	0.548^{***}	0.833^{***}

*** significant at 0.001
** significant at 0.01
* significant at 0.05

Table 3.--First-order linear regression prediction equations and related statistics for measured site index (S.I.) versus each of the four site evaluation methods:
UBB, unmodified Baker Broadfoot method;
MBB, modified Baker-Broadfoot method;
ZR, Zahner regression method;
ZF, Zahner field method

Method	a	b	R^2_{adj}	$F_{(1,49)}$
Model: S.I. =	a +	b * X		
X=UBB:	42.183 +	0.534*X	48.4%	46.08^{**}
X=MBB:	33.960 +	0.611*X	46.8%	43.18^{**}
X=ZR:	68.996 +	0.236*X	7.9%	5.265^{*}
X=ZF	46.784 +	0.497*X	19.3%	12.948^{**}

** significant at 0.001
* significant at 0.05

Table 4.--Chi-square test for accuracy (Freese 1960) between measured site index and each of the four site evaluation methods; tabled values are Chi-square statistics (50 d.f.) for given levels of accuracy

Range	probability of site index prediction falling beyond the desired range of accuracy P < 0.05	P < 0.10
A. Unmodified Baker-Broadfoot Method		
±5'	538.479 NS	379.305 NS
±10'	134.620 NS	94.826 NS
±15'	59.831^{*}	42.145^{*}
B. Modified Baker-Broadfoot Method		
±5'	382.415 NS	269.373 NS
±10'	95.604 NS	67.343^{*}
±15'	42.491^{*}	29.930^{*}
C. Zahner Regression Method		
±5'	1847.954 NS	1301.700 NS
±10'	461.989 NS	325.425 NS
±15'	205.328 NS	144.633 NS
D. Zahner Field Method		
±5'	807.652 NS	568.911 NS
±10'	201.913 NS	142.228 NS
±15'	89.739 NS	63.212^{*}

NS not significant
* significant at P >0.05

DISCUSSION

The two Baker-Broadfoot methods were better tools for site evaluation across the range of sites in this study than either of the methods of Zahner. The unmodified Baker-Broadfoot method had the highest correlation with measured site index; however, the modified Baker-Broadfoot method, with no deduction for the presence of a fragipan, was more accurate.

Speculation as to the superiority of the Baker-Broadfoot methods over the Zahner methods may take several forms. The Zahner methods, especially the regression method, call for careful classification of the site into upland, loessial, or bottomland, and also into zonal and azonal categories. On bottomland sites, the Zahner methods were least accurate; measured site index consistently exceeded that assigned by applying the Zahner methods. The Baker-Broadfoot methods can be applied with a minimum of constraint across a variety of sites.

The Zahner methods account only for soil texture, slope, and surface soil depth, though in an objective fashion. The subjectively derived Baker-Broadfoot methods evaluate a range of edaphic and physiographic factors that influence tree height growth. Thus, the Baker-Broadfoot methods may more appropriately reflect the nature of productivity, despite its subjective derivation. The Baker-Broadfoot methods require no laboratory analysis. However, careful field examination is required; the assistance of a qualified soil scientist may be needed to make accurate estimates of soil texture and structure, soil age, and compaction.

The level of accuracy is lower than desired. None of the soil evaluation methods were within ±5 feet of the measured site index nine out of ten times (as judged at the 95% level of significance). The modified Baker-Broadfoot method is the only method accurate to within 10 feet nine out of ten times.

Part of the poor accuracy in this study may be due to errors in obtaining measured site index. Site index estimates derived using height-age methodology are subject to large measurement error (McQuilken and Rogers 1978). The use of only two trees as a basis for measured site index probably resulted in less precision than one might wish to achieve. For example, several stands in this study have measured site index estimates which differ by more than ten feet from any of the four estimation methods. If the estimation methods themselves are accurate, comparing them to imprecise measured site index values will result in inaccurate site index predictions, and will inspire less faith in the evaluation methods than might be warranted.

These results provide a crudely accurate method of evaluating the productive potential of a site which has no trees. On such sites. estimates of site index to within ±10 feet will provide landowners and foresters with an indication of the productive capacity of the site. Greater accuracy might be achieved by formulating a new Baker-Broadfoot method specifically for loblolly pine on sites in the West Gulf Region of the Southern Coastal Plain. A larger data base, with more site index trees per plot, would be preferable for such analyses.

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RELATING SITE INDEX OF NATURAL LOBLOLLY PINE ON THE LOWER COASTAL PLAIN TO SOME ENVIRONMENTAL FACTORS[1]

Marilyn A. Buford and William H. McKee, Jr.[2]

Abstract.--Soil chemical and physical attributes and stem analysis data were used to develop loblolly pine site index prediction equations for selected soil series on the lower Coastal Plain of South Carolina. Discriminant functions using measured environmental variables correctly classified only 41 and 28 percent of reserve test plots into 10-foot site classes (base age 50). Regressions developed from soil factors accounted for 26 to 99 percent of the variation in site index (base age 50).

INTRODUCTION

Forest site productivity is a function of the physical, chemical, climatic and biological characteristics of the site and its occupants. There have been numerous attempts at developing site productivity prediction systems for many species, including loblolly pine (Pinus taeda L.). Most have attempted to predict site index or site productivity class from some combination of soil, climatic, and vegetative characteristics of the site (Coile and Schumacher 1953, Zahner 1954, McClurkin and Covell 1965, McKee 1976, Broerman 1978, Payandeh 1986, Milner 1988, Monserud 1988). This paper reports the results of a study designed to develop site index prediction equations for loblolly pine based on environmental factors for soil series on the lower Coastal Plain of South Carolina.

METHODS

Data

Between January 1980 and March 1981 105 quarter-acre, circular plots were established in natural loblolly pine stands. To be chosen as a plot location, areas had to: 1) be in relatively undisturbed natural loblolly pine stand in excess of 50 years of age, 2) have 80-120 sq. ft. per acre of pine basal area, 3) contain five or more dominants suitable for stem analysis, 4) appear uniform in mid- and understory composition, and 5) be on a desired soil series. Soil series were initially identified from soil survey maps (SCS 1980). Field classification of each plot was done by Warren Stuck[3]. Final identification was made after physical and chemical analysis of soil samples. Plots were distributed across soil series in the following manner: Nemours (aquic hapludults clayey, mixed, thermic) (34), Yauhannah (aquic hapludults fine-loamy, siliceous, thermic) (7), Yemassee (aeric ochraquults, fine-loamy, siliceous, thermic) (6), Wahee (aeric ochraquults clayey, mixed, thermic) (20), Okeetee (aeric ochraqualfs fine, mixed thermic) (11), Ogeechee (typic ochraquults fine-loamy, siliceous thermic) (1), Yonges (typic ochraqualfs, fine-loamy, mixed, thermic) (1), Pooler (typic ochraquults clayey, mixed, thermic) (6), Meggett (typic albaqualf fine, mixed, thermic) (17), and Santee (typic argiaquolls fine, mixed, thermic) (2). All plots were on a Pleistocene terrace 20 to 35 feet in elevation.

On each plot, species, crown class, Dbh, total height, distance from plot center, and relative position were recorded for each tree larger than 4.6 inches in diameter. Two dominant or codominant trees were felled, bucked into 4 foot sections, and the number of rings were counted at the top of each section. The total age of the tree was assumed to be one year older than the number of rings counted one foot above the ground. A height-age profile for each stem was developed from this information. Mid- and understory species were identified and tallied. In addition, past land use (old rice field, old upland field, or forested site) was recorded for each plot.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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Soil samples were taken from four locations around each of the trees selected for stem analysis. At each point, a sample from the forest floor, from each mineral horizon identified by the soil surveyor, and from 38-42 inches below the surface of the B horizon (considered the C, or control, horizon) was collected. Properties of the soil samples determined were horizon thickness and identification, percent organic matter by wet oxidation, percent sand, silt, and clay, drainage class, total nitrogen (ppm) by Keldahl digestion, available phosphorus (ppm) by Bray P-2 extraction, exchangeable potassium, calcium, magnesium, sodium (meq/100g) and extractable manganese (ppm) by ammonium acetate extraction, pH by 1:1 soil water mixture, and total organic phosphorus (ppm) by the Olsen method.

Analysis

Discriminant analysis and linear regression were used to explore the data for predictive relationships between site index and the measured soil variables. A third method was to examine the past height growth patterns of the sample trees. The plots were grouped in two different ways for analysis: 1) by soil drainage class, and 2) by past land use. The analyses described below were each done with the data grouped by drainage class and then by past land use.

Discriminant Analysis.--Discriminant analysis is a technique of assigning an observation to one of several populations based on a linear combination of the measured attributes of that observation (Morrison 1976). Each plot was classed into a 10-foot site index class based on the dominant height at age 50 on that plot.

With the data grouped by drainage class and then by past land use, a linear discriminant function to classify each plot into a site index class was calculated from 70 percent of the plots selected at random. This subset of the data is called calibration data. In each case the remaining 30 percent of the plots was withheld as test data to assess the reliability of the calculated discriminant function. In all cases, the test data were representative of the calibration data. The random number procedure placed 32 and 29 plots into the calibration data sets for drainage class and past land use groupings, respectively.

Separate discriminant functions were calculated for the moderately well drained, the somewhat poorly drained, and the poorly drained plots. Since only two plots were in the very poorly drained, it was impossible to calculate a discriminant function for that drainage class. The discriminant functions were used to classify the calibration data from which they were calculated and to classify the test data held in reserve.

Using the same procedures, separate discriminant functions were calculated for each past land use represented in the data--old rice fields, old upland fields, and forested sites. The resulting discriminant functions were used to classify the calibration data and the remaining test data.

Linear Regression.--To determine what variables could best be used to describe the variation present in the data, a stepwise regression using all the continuous soil variables to predict the site index of each plot was performed. A significance level of $\alpha = 0.15$ was used to try to avoid overestimation. A regression was calculated for each drainage class group, for each land use group, and for the data set as a whole. The fact that there were only two plots in the very poorly drained group prohibited calculating regressions for this group.

Earlier work (McKee 1976) and long-term observation suggest that site index of loblolly pine on the lower Coastal Plain is related to stand basal area, average tree size, phosphorus concentration in the surface horizon, exchangeable base concentrations, and depth to water table. For each of the drainage class groups, for each of the land use groups, and for all of the data combined, a multiple regression for site index was also calculated from these variables. Depth to mottling was used to estimate the average water table depth over the life of the stand.

Relative Height.--As a measure of height growth pattern or cumulative height-age curve shape, ratios of total height at ages 5, 10, 15, 20, 25, 30, and 40 years to tree height at age 50 years were calculated for each tree. It was felt that patterns in these calculated rates with respect to the measured variables would provide some insight into height growth pattern and, ultimately, site index for these sites. Simple correlations between these ratios and the soil variables in various combinations were calculated and examined for possible patterns.

RESULTS

Discriminant Analysis

The discriminant functions correctly classified 100 percent of the calibration data into 10-foot site index classes whether grouped by drainage class or by past land use. For the test data grouped by drainage class, the discriminant functions correctly classified only 41 percent of the 32 randomly chosen test plots. For the plots grouped by past land use, only 28 percent of the 29 randomly chosen test plots were correctly classified into 10-foot site index classes. Misclassifications were proportionately distributed across the groups. Classification results by site index class are given in tables 1 and 2 for the test data.

Table 1.--Observed and predicted site index classes for the test plots using discriminant functions developed for drainage classes

Site Index Class Observed	Predicted 80	 90	 100	 110	 120
80	1	1	3		
90	1	5	5		
100	2	3	6	2	
110		1		1	
120		1			

Table 2.--Observed and predicted site index classes for the test plots using discriminant functions developed for past land use classes

Site Index Class Observed	Predicted 70	 80	 90	 100	 110	 120
70		1				
80		2				
90	1	2	3	5	1	
100	1	3	4	2	1	
110			1		1	1
120						

Linear Regression

The results of the stepwise regression procedures for drainage class and past land use groups are given in tables 3 and 4, respectively. Values from the A1 and C (control) horizons were used because they were correlated most closely with the plot site indexes. The ratio of potassium to magnesium in the C horizon (K/Mg (C)) is important for the somewhat poorly drained and poorly drained classes. This indicates that minerology may be important in determining site index on some of these sites.

Results from the regression containing only total basal area per acre, the plot quadratic mean diameter, available phosphorus and exchangeable bases in the A1 horizon, available phosphorus in the control horizon, and the depth to mottling were varied. The amounts of variation in site index accounted for were 20 percent for the poorly drained, 47 percent for the somewhat poorly drained, and 20 percent for the moderately well drained group. For the past land use groups, this regression accounted for 94 percent of the variation in site index for the old rice fields, 18 percent on upland old fields, and 28 percent on forested areas.

Table 3.--Results of stepwise regression for site index with plots grouped by drainage class

Variable	moderately well drained	somewhat poorly drained	poorly drained
pine basal area	+[1]		+
pH (A1)	+		
Mn (A1)	+		
clay (C)	+		
organic P		+	
K/Mg (C)		+	+
silt (A1)		+	
N (A1)		+	+
K (A1)		+	+
silt (C)			+
clay (A1)			+
	N=24	N=38	N=41
	R^2=0.87	R^2=0.62	R^2=0.40
Range (ft)	73 - 111	80 - 117	69 - 112
CI width (ft)[2]	14.3	28.8	24.5

[1] + indicates presence in regression
[2] average width of the 95% confidence interval for predicting site index (base age 50)

Table 4.--Results of stepwise regression for site index with plots grouped by land use history

Variable	rice field	upland field	not old field
pine basal area	+[2]		+
pine qmd[1]	+		
Mn (A1)	+		
stand qmd	+		
K (A1)	+		
Mn (C)	+		
mottling depth	+		
K (C)		+	
Mg (C)		+	
silt (C)			+
clay (A1)			+
organic P (A1)			+
Mg (A1)			+
pH (A1)			+
P (A1)			+
	N=9	N=38	N=58
	R^2=0.99	R^2=0.26	R^2=0.57
Range (ft)	93 - 112	85 - 117	73 - 109
CI width (ft)[3]	0.61	30.1	24.0

[1] qmd = quadratic mean diameter
[2] + indicates presence in regression
[3] average width of the 95% confidence interval for predicting site index (base age 50)

The multiple regression equation developed for the data set as a whole contained total pine basal area per acre, total organic phosphorus in the A1 horizon, and exchangeable calcium and magnesium in the control horizon accounted for 39 percent of the variation in site index. The overall equation containing total basal area per acre, plot quadratic mean diameter, exchangeable bases, available phosphorus in the A1 horizon, and depth to mottling accounted for only 20 percent of the observed variation in site index.

Examination of scatter plots of the correlation of each of the relative height ratios (ratio of height at a given age to the height at age 50) with the measured soil and stand variables measured revealed no discernible patterns or trends. It was therefore not possible to model change in the shape of the cumulative height-age curves for these plots.

CONCLUSIONS

The discriminant functions developed from these data were inadequate for classifying observations from the same population that had been held back during equation development. The equations were able to correctly classify only 41 and 28 percent of the test observations when grouped by drainage class and land use history, respectively.

Efforts to relate the shapes of the cumulative height-age curves to the environmental variables measured were unsuccessful.

There were few similarities among the site index prediction equations obtained through the stepwise multiple regression technique, regardless of grouping. The amount of observed variation in site index accounted for by these equations varied from 26 to 99 percent. A multiple regression equation developed without regard to drainage class or land use history accounted for 39 percent of the observed variation in site index. Total pine basal area per acre is present in five of the seven regression equations developed through the stepwise technique. Presence of pine basal area should be expected because its production is positively correlated with site quality (Strub and Bredenkamp 1985). The average width of the 95 percent confidence interval for predicting site index from the stepwise regression equations ranges from 0.61 feet to 30.1 feet. Except for the old rice field sites, these confidence interval widths indicate an overall lack of precision for predictions from these equations.

The descriptive and predictive ability of the functions developed here is generally poor. This result is similar to those of other studies seeking to relate site index to soil variables. Tree height growth is a dynamic process. Changes in soil and other environmental conditions create variation in height growth throughout the life of the tree. Site index is a measure of the cumulative result of varied growing conditions through some base age, e. g., 50 years. It is not surprising, then, that values of environmental parameters at one point in time do not yield useful predictions of site index. Future studies aimed at predicting site index should include dynamic measures of environmental variables rather than static measures.

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Compartment 17 is in the lower end of the basin, on an intermountain area with low relief and Piedmont-like terrain. Elevations in the 43-acre area studied range from 2,160 to 2,260 feet. The area occupies the mid to lower portion of a 2,700 feet long, south-facing slope. The main slope has a uniform 6- to 8-percent gradient, but side slopes of several small drains range to 20 percent. Soils are mostly eroded Hayesville loam, a common series on broad ridges and relatively level areas of intermountain basins, that develops in residuum over gneisses. Hayesville is relatively low in productivity with site index of 66 for shortleaf pine. Small areas of Tate-French loam were mapped in alluvium in an upland drain and beside a second-order stream. Both series are Typic Hapludults with solum depth greater than 40 inches. In all respects, site conditions in the study area appear homogeneous and typical of many sites of low to moderate quality in intermountain basins.

The present timber stand, which developed after clearcutting in 1967, consists of 21-year-old hardwoods with some pines. The previous stand originated on abandoned agricultural land around 1890 and was mainly conifers and some hardwoods. Timber harvested averaged 2,791 bd ft/ac of yellow pine, 535 bd ft/ac of yellow-poplar, and 395 bd ft/ac of mixed oaks.[3] Site preparation consisted of clean felling residual stems greater than 4.5 feet in height.

A 1985-inventory revealed about 435 free-to-grow stems and 51 ft^2 of basal area per acre in all stems greater than 1-inch dbh. The principal species, listed by percent occurrence on a systematic grid of 43 permanent, 1/40-acre sample plots, were: red maple (Acer rubrum L.) 100%, white oak (Quercus alba L.) 81%, yellow-poplar (Liriodendron tulipifera L.) 70%, scarlet oak (Q. coccinea Muenchh.) 67%, black oak (Q. velutina Lam.) 65%, shortleaf pine (Pinus echinata Mill.) 63%, Virginia pine (P. virginiana Mill.) 47%. Subcanopy hardwood species include mainly dogwood (Cornus florida L.), sourwood (Oxydendrum arboreum (L.) DC.), and, in some areas, American holly (Ilex opaca Ait.). A prominent tall shrub vegetative layer is dominated by ericaceous species, mainly mountain laurel (Kalmia latifolia L.) and some flame azalea (Rhododendron calendulaceum (Michaux) Torrey). Several species of blueberry (Vaccinium sp. L.) and huckleberry (Gaylussacia sp. HBK.), also in the Ericaceae family, formed a uniform, low shrub cover. Bracken fern (Pteridium aquilinum (L.) Kuhn.) was present throughout the area.

METHODS

Topographic components of landtype association, landtype, and landtype phase were evaluated on 50 circular, 1/100-acre sample plots, subjectively located to represent typical and extreme site conditions. Topographic variables measured were major landform, aspect, slope position, gradient, and land surface shape of the plot and area surrounding the plot as quantified by the terrain shape index (McNab, In press). Soil variables included series, thickness of the organic (O) horizon, and thickness of the A+E horizons. Vegetation variables included presence and an index of area covered by each nonarborescent plant species or species group found on the 1/100-acre sample plot. Only common and easily seen species present during the late summer were recorded. Vegetation was recorded by species with two exceptions; all species of blueberry and huckleberry were combined into a huckleberry group, and a fern group included mainly New York fern (Thelypteris noveboracensis (L.) Nieuwland) with lesser amounts of southern lady fern (Athyrium asplenioides (Michaux) A. A. Eaton). An index of density of stocking of understory species was computed by subdividing the 1/100-acre sample plot into ten 1/1000-acre subplots, and summing the number of subplots in which a species occurred.

Response of arborescent vegetation to site quality of the sample plots was determined by measuring total height of six species: shortleaf and Virginia pine, scarlet and white oak, red maple and yellow-poplar. One dominant or codominant tree of each subject species occurring on the 1/100-acre sample plot was measured for total height. To increase sample size, trees adjacent to the 1/100-acre plot were also measured where similar site conditions were present.

A combination of scatter plotting and correlation analysis was used to determine the subcomponent variables related to site quality. Multiple regression was then used to model the relationship of tree height to topography, soil, and vegetation. Finally, the single most important variable in each subcomponent was selected for development of a combined model.

The combined model was applied to a grid of 43 permanent plots in the study area to (1) determine average time required to evaluate site quality, and (2) identify topographic variables associated with the forest cover type at each sample point. These plots were 1/40-acre in size and were separate from the 1/100-acre plots used to sample tree heights. Times were read to the nearest minute for measurement of topographic, soil, and vegetation variables on each plot. Also, SAF forest cover type (SAF 1980) was noted at each plot. Scatter plotting and analysis of variance were used to evaluate the relationship between cover type and two topographic variables: gradient and area surface shape.

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[3] Ralph M. Hooper, 1981. Rice Pinnacle Clearcut. Office Report on file at Bent Creek Experimental Forest.

RESULTS AND DISCUSSION

Evaluation of Site Variables

Total heights for 221 sample trees were measured. Mean heights of the six species varied from 35 to 45 feet (figure 1). The range in total heights was greatest for yellow-poplar (37 feet), followed by red maple (31 feet). The range in heights was least for shortleaf pine (12 feet). Most hardwoods sampled probably originated from stump sprouts or large advance regeneration. For example, 98% of the yellow-poplar trees measured were multistemed as were 92% of red maple, and 52% for each species of oak. Except for some of the oaks, much of the range in tree height may be assumed to be a response to site quality and not differences in vigor resulting from seedling compared to sprout origin.

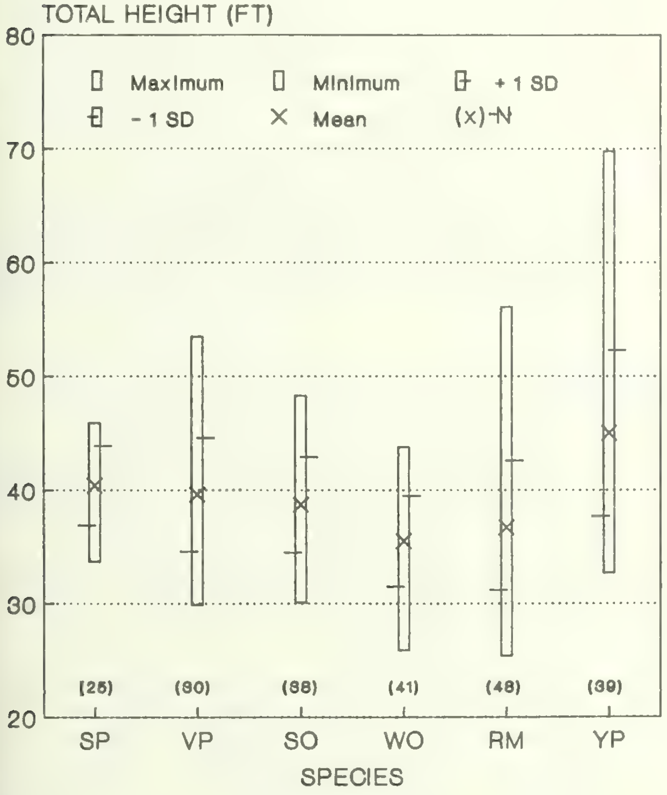

Figure 1.--Means, ranges, and standard deviations in total height of six tree species sampled in a 21-year-old clearcut on a low-to-medium quality site in Bent Creek Experimental Forest, NC. The number of trees sampled in each species is in parentheses below each bar. (SP = shortleaf pine, VP = Virginia pine, SO = scarlet oak, WO = white oak, RM = red maple, YP = yellow-poplar.)

Correlations were determined between total height of each species and the measured site factors (table 1). In the hierarchy above landtype phase, topography was largely uncorrelated with tree height for all species except scarlet oak. Land surface shape of the plot and the area surrounding the plot was significantly correlated with height of all hardwood species, but was of lesser importance for the pines. Correlations between height and slope gradient were weak for all species except Virginia pine.

Table 1.--Simple correlation coefficients of total height of six dominant and codominant species with topographic variables in a 21-year-old clearcut on a low-to-moderate quality site in Bent Creek Experimental Forest, N.C.

	- -Landtype - - -		- - -Landtype phase- - - - -		
Tree species	Sine of azimuth	Slope position	Slope gradient	Land surface shape Plot	Area
Shortleaf pine	-0.05	0.36	-0.23	0.28	0.21
Virginia pine	0.02	-0.12	0.49*	0.37*	0.20
Scarlet oak	-0.43*	-0.05	0.04	0.59*	[illegible]*
White oak	-0.14	0.05	-0.25	0.60*	[illegible]*
Red maple	-0.12	-0.18	-0.18	0.65*	[illegible]*
Yellow-poplar	-0.03	0.06	-0.19	0.72*	0.37*

* Denotes significant at the 0.05 level of probability.

Tree height was correlated with several soil and vegetation variables (table 2). No strong correlations were present between height of any tree species and soil series or thickness of the O horizon. However, heights of white oak, red maple, and yellow-poplar were strongly correlated with thickness of the A+E horizons. Soil series might be more important when sampling is done over broader geographical areas.

Fifteen shrub and herbaceous species were recorded on the sample plots; tree height was correlated with the density index of five of these (table 2). Total height of all sample tree species except shortleaf pine was strongly directly correlated with the density index of the ferns. Conversely, for all but two tree species there were strong negative correlations between tree height and the density index of the huckleberry group. Correlations were inconsistent for mountain laurel and Virginia creeper, and probably are only artifacts of the data set.

Table 2.--Simple correlation coefficients of total height of six dominant and codominant species with soil variables and abundance of five commonly occurring understory species in a 21-year-old clearcut on a low-to-moderate quality site in Bent Creek Experimental Forest, N.C.

Tree species	Landtype Soil series	- - - - - - - Landtype phase - - - - - - -						
		- -Horizon- -		Understory species1/				
		O	A+E	THNO	KALA	PAQU	CEOR	GASP
Shortleaf pine	.00	.32	.25	.30	-.12	-.06	-.08	-.15
Virginia pine	.00	-.03	.07	.38*	-.31	.51*	.52*	-.50*
Scarlet oak	- .12	-.10	.10	.36*	.33*	-.03	.38*	-.34*
White oak	- .14	.04	.46*	.35*	-.04	.03	.10	.22
Red maple	- .02	-.05	.44*	.58*	.01	.12	.55*	-.62*
Yellow-poplar	.04	-.27	.59*	.72*	.06	.31	.47*	-.68*

1/ THNO: *Thelypteris noveboracensis* (New York fern); KALA: *Kalmia latifolia* (Mountain laurel); PAQU: *Parthenocissus quinquefolia* (Virginia creeper); CEOR: *Celastrus orbiculatus* (Oriental bittersweet); GASP: *Gaylussacia* spp. (miscellaneous huckleberries).

* Denotes significance at the 0.05 level of probability.

Correlations between tree height and the presence or absence of most shrub and herbaceous species were weak and not significant. Although the presence of several species, especially New York fern, oriental bittersweet, and huckleberries was strongly correlated with tree height, variation was so great that the presence-absence data would be almost useless for estimation of site quality. In comparison with the density index, the mere presence of species was a relatively crude measure of vegetation present on a plot.

Multiple correlation coefficients and standard errors of estimate are shown in table 3 for significantly correlated variables in each subcomponent using the following models:

Topographic model:
Total height = b0
+ b1 (slope gradient)
+ b2 (land surface shape of plot)
+ b3 (land surface shape of area). [1]

Soil model:
Total height = b0
+ b1 (thickness of A+E horizons). [2]

Vegetation model:
Total height = b0
+ b1 (density index of New York fern)
+ b2 (density index of oriental bittersweet)
+ b3 (density index of huckleberries). [3]

Variation in height of all species except shortleaf pine showed significant correlation with at least one of the three models (table 3). Heights of the non-oak hardwoods were particularly strongly correlated with the vegetation model.

Table 3.--Multiple correlation coefficients (R^2) and standard errors of estimate (RMSE) by tree species and prediction model for sample trees in a 21-year-old clearcut on a low-to-moderate quality site in Bent Creek Experimental Forest, NC.

Model parameter	Model 1 (topography)	2 (soil)	3 (vegetation)	4 (combined)
		SHORTLEAF PINE		
R^2	0.12	0.06	0.13	0.09
RMSE	3.52	3.47	3.50	3.57
		VIRGINIA PINE		
R^2	0.36*	0.01	0.38*	0.36*
RMSE	4.20	5.06	4.14	4.22
		SCARLET OAK		
R^2	0.36*	0.01	0.21*	0.46*
RMSE	3.47	4.19	3.84	3.17
		WHITE OAK		
R^2	0.39*	0.21*	0.12	0.38*
RMSE	3.23	3.58	3.87	3.24
		RED MAPLE		
R^2	0.45*	0.20*	0.52*	0.55*
RMSE	4.51	5.35	4.24	4.09
		YELLOW-POPLAR		
R^2	0.55*	0.34*	0.64*	0.70*
RMSE	5.09	5.99	4.58	4.18

* Denotes model significant at 0.05 level of probability.

In addition, the combined influence of all subcomponents in the landtype phase was evaluated by including the strongest variable from models 1, 2, and 3:

Combined model:
Total height = b0
+ b1 (plot land surface shape)
+ b2 (thickness of A+E horizons)
+ b3 (density index of huckleberries). [4]

This general model improved multiple correlations for some species, and reduced standard errors of estimates (table 3). At this level in the hierarchy, variables from several subcomponents seem to be superior to a single subcomponent for predicting tree height.

Other models based on various combinations of site variables can also be developed, depending on the planned uses. In this uniform study area, for example, soil variables alone or in the presence of a vegetation subcomponent contributed little to reducing variation in estimates of tree height. Therefore, it might be desirable to develop a model based only on topographic and vegetation indicators. However, application of such a model would be difficult during the dormant season when deciduous indicator species might not be apparent. In such a circumstance, a model based on topographic and soil variables would be desirable. Models with combinations of variables such as these were not investigated due to the restricted data base and limited scope of the study.

The study design tested mainly the response of tree height growth to the site factors measured in the landtype phase component. The study was done in a single large but homogeneous area where variation from other typically measured site factors such as soil series, aspect, slope position, and slope gradient was not great. Also, because the stand was even-aged, tree age was excluded as a confounding factor. In models where age is included as an independent variable, it typically accounts for a large proportion of the variation in tree height and usually overshadows the effect of the other site factors. Where landtype phase is evaluated in many stands, a large sample will likely be needed to partition variance among the many factors that affect tree growth.

Application of Combined Model

A total of about 4 minutes per plot were needed to collect field data required for application of the combined model [4]:

Subcomponent	Time ± s.d. (Minutes)
Topography	1.5 ± 0.55
Soil	1.3 ± 0.50
Vegetation	1.3 ± 0.53

Slightly more time per plot (0.6 minute) was required to measure variables in the yellow-poplar cover type, probably as a result of thicker A+E horizons and higher density of understory species.

Forest Cover Type Model

Forest cover types and percent of plots occurring in each type were Virginia pine-oak (44%), white oak (33%), and yellow-poplar (23%). The need for a forest cover type model is demonstrated by the distribution of yellow-poplar in the study area. Yellow-poplar was present over a wide range of sites, including many plots on upland areas, and was consistently the dominant species. On most upland areas, however, yellow-poplar was a minor component among the oaks, usually represented by only several trees per acre. Even though it grew well in height, yellow-poplar generally had poor form and did not seem to be best suited to these sites. O'Hara (1986) reported a similar situation with yellow-poplar in the N.C. Piedmont. Without applying a forest cover type model, the entire 43-acre area would be predicted to be dominated by yellow-poplar, even though oak and pine species formed the overstory canopy on most upland sites.

Scatter plotting revealed that cover type was strongly related to area surface shape, but not to gradient (figure 2). Univariate analyses of variance indicated that the yellow-poplar cover type was mainly associated with areas having a concave shape, while the oak and pine cover types were generally found on linear to convex areas. A multivariate analysis is needed to more completely explore these and topographic relationships from other components. Based on these preliminary findings, however, development of models for predicting cover type using topographic features appears to be attainable.

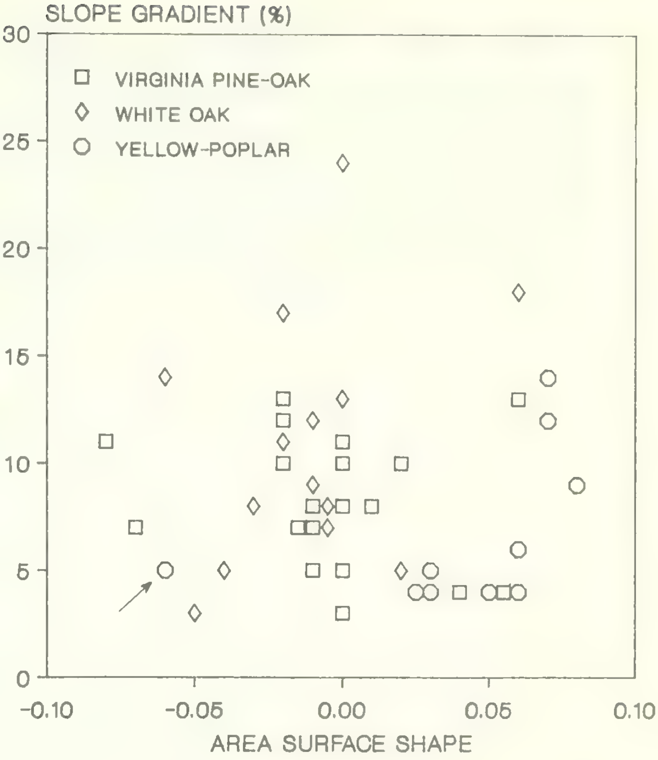

Figure 2.--Relationship of SAF forest cover type with gradient and area surface shape in a 21-year-old clearcut on a low-to-medium quality site in Bent Creek Experimental Forest, NC. The stand identified by an arrow is discussed in the text.

An example of the importance of vegetation in evaluating site quality at the landtype phase level is also illustrated by figure 2. Note the plot dominated by yellow-poplar that is identified with an arrow. As indicated by the measure of area surface shape, this plot occurred on a slightly convex site and application of the yellow-poplar topography model [1] would have resulted in a prediction of total height much below actual. However, application of the combined model [4], which includes a vegetation variable, would produce a much more accurate estimate of total height because of an abundance of New York fern and a scarcity of huckleberry on the site. For this plot at least, herbaceous vegetation indicated the presence of certain soil moisture or fertility conditions favorable for yellow-poplar growth that were not associated with topographic variables.

CONCLUSIONS

Results from this study suggest that several site-specific variables are strongly correlated with site quality, even in restricted areas of relatively uniform topography, and are useful in a taxonomic site classification system. In intermountain basins, and other areas of greater relief but with consistent aspect and slope position, microtopography appears to be a useful subcomponent to include in models for predicting site quality or tree height at a given age. Other site-specific subcomponents, such as thickness of the A+E horizons and a measure of abundance of certain understory indicator species are also likely to be important in indirect estimation of site quality. In addition, prediction of overstory cover type seems to be feasible using subcomponents such as topography. Further study of these relationships seems desirable in stands on other landtype associations, such as coves and ridges.

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DISCRIMINANT EQUATIONS FOR MIXED MESOPHYTIC OLD GROWTH AND SECOND GROWTH FOREST TYPE CLASSIFICATION AS EXTRAPOLATED TO MINE SPOILS FOUND IN EASTERN KENTUCKY.[1]

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Bart A. Thielges and Kenneth W. Farrish[2]

Abstract.--Step-wise discriminant analysis was used to develop two equations containing five variables that classified Beech, Sugar Maple and Chestnut Oak-Red Maple old growth forest types in the Lilley Cornett Woods of eastern Kentucky. The results indicate that these analytical procedures can be used as a guide to select the best site conditions for forest type reestablishment on mining spoil.[3]

INTRODUCTION

The mixed mesophytic forest of the eastern United States is noted for its unique groupings of the numerous component species (Braun 1942, 1950). Braun (1950) stated that the diverse forest species of the area exist on dissimilar soils which support an exceedingly rich and diverse herbaceous layer as well. Muller (1982) notes that not only are these forests rich in species composition but they are also highly diverse in terms of site conditions.

Climate, topography and soil have long been recognized as major components in the classification of site factors. Muller (1982) used components of these factors to determine site differences important to species distribution. Others imply similar findings. Whittaker (1956) observed strong gradients of species distribution relative to moisture, as determined by aspect and topography of the site, and the complex of environmental conditions associated with elevation in the Great Smoky Mountains. Cove forest studies of the same area have also shown a partial relationship between species distribution and soil pH (Schmalzer et al. 1978). Fowells (1965) and Hutchins et al. (1976) recognized that the diversity in soil fertility from one site to another might be an important determinant in species distribution in the mixed mesophytic forest. Bush (1982) observed that forest growth and successional patterns are often correlated with variations in soil and topography as well as with climate and geomorphological processes.

Surface mining in eastern Kentucky significantly alters the natural forest soils and topographic character of the land. It is logical to assume that the forest species associations capable of existing on these disturbed areas would change as well. Different species of trees and shrubs have been extensively tested on mining spoil for wood production, wildlife habitat, and recreation needs (Plass 1978). This research has raised many questions both about plant growth potential immediately after reclamation and about the capability of spoil to support plant growth over long periods of time. A major problem is that survival and growth information from individual studies frequently do not include mining spoil site properties.

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[1] Paper presented at the Fifth Biennial Southern Silvicultural Research Conference, Memphis, Tennessee, November 1-3, 1988.

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[3] Research Supported through McIntire-Stennis ooperative Forest Research Program (Public Law 7-788).

Consequently, these results are restricted to site-specific observations of plant growth and yield that cannot be applied to newly reclaimed sites. Past mining spoil research has in many cases disregarded site characteristics necessary for the survival and growth of a plant species or groups of species.

This study attempted to recognize the uniqueness of existing old-growth forest type sites; to define these uniquenesses with discriminant analysis; to test findings with second-growth forest type information and to extrapolate that information to classify mining spoil sites.

METHODS AND PROCEDURES

Study Sites

The forest type distribution study was conducted on the Lilley Cornett Woods, a 148 ha preserve located on the eastern edge of the Cumberland Plateau in Letcher County of eastern Kentucky. The study by Muller (1982) was of special interest because it used stand characteristics to divide old-growth and second-growth forest watersheds into three forest types. Muller (1982) segregated these three forest types on the basis of an analysis of 80 old-growth and 80 second-growth forest sites which he found to be similar in species composition. The three forest types were defined as Sugar Maple, Beech, and Chestnut Oak-Red Maple. The soils of each forest type exhibited very specific characteristics, many of which were significantly different from one another.

This forest type evaluation was centrally located to a mining site study where 122 plots on nine surface mines in nine counties in the Appalachian coal region of the eastern Kentucky Cumberland Plateau were examined (Rowell 1984). The procedures used in both studies to analyze nitrogen, potassium, phosphorus, calcium, magnesium, pH, available water capacity and radiation index were the same.

Laboratory Analysis

Soil samples for both studies were air-dried,ground, and passed through a 2mm sieve. Total nitrogen (N), extractable phosphorus (P), exchangeable potassium (K), calcium (Ca), and-magnesium (Mg) were determined according to methods practiced by the University of Kentucky Experiment Station Soil Testing Laboratory. Values were expressed in kg/ha. A 1:1 water/spoil suspension by volume was used to measure pH. Available water capacity was estimated by pressure membrane methods and was reported as the difference between field capacity (-33 kPa atmospheric tension) and permanent wilting point (-1500 kPa atmospheric tension). Soil nutrient values from Muller's (1982) study were modified to kg/ha in 15cm of depth making them compatible with the mining spoil data. Radiation index for each site was derived from a combination of slope, azimuth and latitude (Frank and Lee 1966).

Data Analysis

A step-wise discriminant analysis procedure was used with the old-growth forest data to derive equations that would separate the three forest types. The equations were validated for reliability using 80 known second-growth forest type plots. The ranges of the selected variables in the equations were used to identify mining spoil sites that had within range values. The selected mining sites were classified with the discriminant equations to assess which forest type the selected spoil material would likely support. The Statistical Package for the Social Sciences (Nie et.al. 1975), and the Statistical Analysis System (SAS 1979) were used for all statistical calculations and procedures.

Basic statistical analyses were performed on all measured and derived variables of the two studies to establish summary site/stand information with means, standard deviations, and ranges of site values. No prior assumptions were made about site relationships.

RESULTS AND DISCUSSION

In the Mixed Mesophytic Forest of eastern Kentucky, many forest types exist (Braun 1950). Each of these has a set of site/stand characteristics that are unique and, though they are continually changing, give rise to distinct species composition at a given successional stage of forest development (Bush 1982).

The original data from the Lilley Cornett Woods study (Muller 1982) was re-analyzed using eight variables common to those obtained from the 122 mining spoil sites. The mean values of these variables for the three old-growth forestry types and the mine spoil are presented in table 1. The ranges of values of the eight variables from the old-growth forest (Muller, 1982) and the mining spoil (Rowell 1984) are compared in table 2. The overlap of some or all of these ranges in the old-growth forest with those of the respective ranges from mining spoil sites is important; the common ranges indicate possible similarities between the nutrient and water availability status of the mining spoils and the forest soils.

Step-wise discriminant analysis was used to select only the most effective of these eight variables in defining the three forest types mathematically. Two equations and five variables were chosen which when plotted (fig. 1) correctly classified the 80 plots of the old-growth forest type 76% of the time (table 3). It is not suggested that the five variables considered in table 3 are the only indicators of significant forest type differences in eastern

Kentucky. However, of the eight variables common to the two studies these five variables produce the best discrimination among the site characteristics of the old-growth forest types.

The five variables selected for the equations demonstrate the complex interactions necessary to distinguish the vegetative character of the area. Most notably, the forest type differences are characterized by available water capacity, soil fertility (Ca, K and pH), and topographic variation (Radiation Index) as summarized by Muller (1982). Of the five variables analyzed, only available water capacity was not significantly different among all three forest types according to Muller's (1982) analysis (table 2). However, available water capacity was third in importance in defining the three forest types by discriminant analysis (table 3). Soil fertility was represented in the equation by Ca, K and (indirectly) pH. In each case, the separation of these three site variables among forest types was significant according to Muller (1982).

Table 1.--Selected site variables of three forest types on an old-growth watershed and 122 mining spoils in eastern Kentucky (adapted from Muller 1982 and Rowell 1984).[1/]

Variable	Forest Type Mean Values BEECH (n=31)	SUGAR MAPLE (n=17)	CHESTNUT OAK RED MAPLE (n=32)	MINING SPOIL (n=122)
Radiation Index	72.0bc	44.0ac	87.5ab	62.3
pH	5.2bc	5.6ac	4.8ab	6.7
N (kg/ha)	3800.0c	4200.0c	2200.0ab	2195.7
P (kg/ha)	9.1	11.7c	7.8b	8.7
K (kg/ha)	358.7bc	517.8ac	307.1ab	151.8
Ca (kg/ha)	1806.8bc	2974.7ac	457.3ab	1367.4
Mg (kg/ha)	416.9c	504.4c	107.6ab	741.7
Available Water Capacity	14.0c	16.0c	18.4ab	17.2

Radiation index was the second variable chosen for the model and it reflects the importance of slope and aspect in discriminating between the three forest types.

Only data describing the three old-growth forest types were used for the discriminant procedure. Obviously, other forest site information when added to the analysis, could change not only the order of importance of the variables but also the variables used for differentiation. However, if data from other areas in eastern Kentucky are limited to the range of values found in the old-growth forest data, then the discriminant score results should be valid.

Table 2.--Range comparisons for site characteristics of an old-growth forest and 122 sites mining spoil sites in eastern Kentucky.

Variable	Forest Soil Range low	 high	Mining Spoil Range low	 high
pH	4.4	6.7	3.9	8.5
Radiation Index	9.1	99.5	7.6	99.6
Nitrogen (kg/ha)	1748.5	7958.0	632.7	5037.6
Phosphorus (kg/ha)	3.3	123.3	1.4	30.8
Potassium (kg/ha)	128.9	562.6	38.4	289.2
Calcium (kg/ha)	100.9	4158.4	179.3	3749.2
Magnesium (kg/ha)	31.4	589.6	159.2	2684.7
Available Water Capacity	7.2	25.8	4.2	29.8

The second-growth forest data from Muller's (1982) study were used to test the old-growth discriminant equation for reliability. He emphasized the similarity of the second-growth forest to the old-growth forest in species composition, topography, aspect and geologic substrate. In a study on forest regrowth and productive management, Muller (1983) again states that these two watersheds differ only in area and management history implying that the regrowth potential of the second-growth forest to be a replicate of the old-growth forest is quite high. The similarities between the two forests justify the use of the second growth data to validate the old-growth discriminant equations. The values from the two equations when plotted were able to correctly separate the forest types of the second-growth forest in 79%

[1/] Values in a row followed by the same letter do not differ significently at the 0.05 level.

Table 3.--Discriminant equations developed to classify the three eastern Kentucky old-growth forest types defined by Muller (1982).

Variable[1/]	Discriminant Equations Function 1	Function 2	F-value at Entry
Calcium (kg/ha)	0.0008	-0.0012	30.97**
Radiation Index	-0.0283	-0.0137	22.44**
Available Water Capacity	-0.0379	0.1932	18.64**
Potassium (kg/ha)	-0.0020	0.0089	14.57**
pH	1.1849	1.5176	12.01**
Constant	-3.7392	-11.0247	

[1/] The summation of variable values multiplied times column value will provide discriminant score.

of the 80 cases suggesting a general applicability of the technique to many forested areas of eastern Kentucky. However, the use of and reliance upon the discriminant equations to define similar forest types on other sites must be limited to areas where site variability falls within the range of the data from which the discriminant equations were derived.

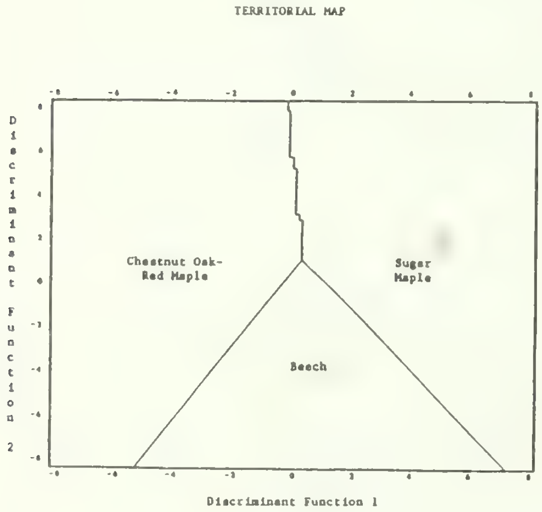

Figure 1.--Two dimensional map of the discriminate functions used to classify three eastern Kentucky old-growth forest types defined by Muller (1982).

Major variation in fertility, moisture availability and topographic differences exist among mining spoils (Rowell 1984). To prevent inappropriate application of the discriminant equations to spoil material not at all like the old-growth forest sites, the ranges of the five variables employed to separate the forest types were used, as a group, to select comparable mining sites. The five variables (Ca, K, pH, radiation index and available water capacity) from the selected mining spoil sites were then used in the discriminant equations (table 4) to compute scores to distinguish these spoils on the basis of their similarity to one of the three forest types.

Thirty-one spoil sites of the 122 had values within the forest site range for Ca, K, pH, Radiation Index and Available Water Capacity. The ability to match 31 mining spoils to known forest conditions was encouraging in that many more sites exist in the Mixed Mesophytic Forest than those defined by the Muller (1982) data. The examination of these other forest types will broaden the base of knowledge for known natural forest conditions allowing for the inclusion of other mine sites in a similar selection process. Encouraging also was the ability of discriminant

Table 4.--Eastern Kentucky mining sites selected for discriminant analysis by comparison to the three forest types of the Lilley Cornett Woods (Muller 1982).

Mining Spoil	Age[1/] 2	3	4	5	6	7	8	9	10	Total Plots
No. Sites	5	14	15	22	22	4	6	17	17	122
No. Selected	1	-	3	7	3	2	4	5	6	31
Forest Type										
Beech	0	-	1	3	2	1	3	1	2	13
Sugar Maple	1	-	2	3	0	1	0	3	3	13
Chestnut Oak - Red Maple	0	-	0	1	1	0	1	1	1	5

[1/] Spoil age classified from time of reclimation.

analysis to further define the selected mining sites. When the discriminant equations were used for classification (table 3) and values plotted (fig. 1), 13 spoil sites were defined as Beech sites, 13 as Sugar Maple sites and five as Chestnut Oak-Red Maple sites (table 4). This ability to classify mining sites into potential forest type areas in important in its ability to reduce errors in off site planting, thus increasing the probability of successful plant community re-establishment on disturbed lands.

CONCLUSIONS

These results indicate that if the reclamation objective was to establish one of the three forest types defined by Muller (1982), then from a total of 122 mining spoils sites only 13 Beech, 13 Sugar Maple and five Chestnut Oak-Red Maple sites could be selected onthe basis of their potential to support these associations. The procedure can be applied to the process of species evaluation and used to increase the probability of success (or reduce errors) in species-site matching. Upon sampling and analyzing other forest types and associations, it should be possible to characterize other mining spoil sites that would meet these new chemical and physical requirements, thus improving the potential for reestablishment of diverse forest types after mining. A further extension would be to use discriminant analysis to define and separate in equation form the diverse site characteristics of known forest types. This information could aid in matching species requirements to new sites, thus significantly improving the probability of successful vegetation establishment on new forest lands and disturbed areas.

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DEVELOPING A SITE SUITABILITY GUIDE FOR MANAGEMENT TYPE RECOMMENDATIONS ON THE CHATTAHOOCHEE NATIONAL FOREST 1/

Richard D. Rightmyer 2/

Abstract.--Direct estimates of site potential are often difficult in the cut-over stands found on the Chattahoochee National Forest. A guide is described for evaluating soil and site characteristics to aid in estimating site potential and selecting species suited to the site. A predicitive matrix format is used to make recommendations based on field measure of soil and site factors. The guide was field tested in 1988; preliminary data indicates sites are often misclassified without the use of soil/site data. 3/

INTRODUCTION

Classification of site potential and making selection of suitable species for management has long been a concern of foresters; particularly when direct estimate of productivity is not practical. High grade harvesting of the early 1900s with little reforestation often created stands where accurate prediction of site potential is difficult from the existing stems. A method has been sought to evaluate site potential of such stands on the Chattahoochee National Forest in Georgia and aid in recommending suitable commercial species for these sites. In addition increased concern from the public about conversion of hardwood stands to pine and a desire to use low-cost techniques for regeneration supports the need for improved site classification. With this challenge a guide has been developed which provides an indirect measure of site potential using field evaluation of soil and site characteristics.

SITE QUALITY STUDIES

In developing the Chattahoochee Guide a review of current literature was done to help decide soil and site factors most critical to growth and perhaps those easy to measure on the site.

Measurement of site quality is an age-old problem of forest management with numerous efforts completed in ways to measure different sites and work with different species. Heiberg and White (1956) defined site as a complex of many factors influencing development of a forest and that a forester must be aware of all the effective factors contributing to this development.

Carmean (1975) produced an exhaustive report on forest site quality evaluation. He states that the first step to intensive forest land management is to determine productive capacity and site quality of the land for alternative tree species. With this task completed one can compare potential yields so that the most productive and valued species for the site can be selected. The problem arises when deciding to use direct or indirect measures of the site potential.

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3/ Henry McNab, Research Forester, Southeastern Forest Experiment Station, provided the data analysis and support for this study.

Direct estimation can be used where age and height can be measured from free to grow, dominant or codominant trees on the site. Where trees are not present or unsuitable due to past management one must use indirect estimates. In stands of this description the relationship of soil and site factors to growth of commercial timber species can be measured to predict growth of a desired species.

Carmean (1970) indicates soil depth, soil texture, soil porosity and parent material are always critical. These characteristics influence the quality and quantity of growing space for roots. In particular his work has shown that changes in the depth of the surface layer; the zone where nutrients and available moisture are most abundant, are the most significant to tree growth.

Soil texture influences the content and movement of moisture; levels of organic matter and the cycling or availability of nutrients (Eigel et al. 1982). Medium textured soils have higher productivity than coarser textured due to higher levels of organic matter, less nutrient leaching and better moisture holding conditions.

Other studies have shown that elevation, slope position and aspect influence site potential. Higher productivity for hardwood is generally found on north facing slopes; lower on south facing slopes (Doolittle 1957, Trimble and Yawney 1968, Trimble and Weitzman 1956). This is generally attributed to increased soil moisture and deeper rooting depths on the north aspects.

A study in the north Georgia mountains identified organic matter content, thickness of the A2 horizon and clay content of the B horizon as predictors of height growth (Ike and Huppuch 1968). Study of six hardwood species and four pine species also found slope position, slope exposure and slope steepness to be strong indicators of site potential. As an example, northern red oak was rarely found on south-facing slopes and exhibited higher site index on lower slope positions. Yellow-poplar was at its best in the open coves and on sheltered lower slopes; at its poorest on the ridges and rarely found on southeast, south and southwest facing slopes.

DEVELOPMENT OF CHATTAHOOCHEE GUIDE

In order to develop a site suitability guide which required minimal field measurement and data collection it was decided to select variables which could be easily defined and identified. Based on review of past studies it was decided to use topsoil depth, solum depth, soil texture, landform position and aspect. A guide was developed in matrix format allowing the user to evaluate soil and site factors in the woods; predict site potential for different species and recommend a species for the site.

Use of the guide in the field requires measurement of topsoil depth; identification of landform position from a topographic map or on the site; identification of soil texture in the upper 24 inches of soil material and measure of aspect. Solum depth is estimated from information in a soil survey report. The guide can be utilized on a stand basis but it is generally desirable to traverse the entire stand; observe average site conditions and develop recommendations for the species best suited to the stand. An example of a portion of the guide is shown in Table 5 at the end of this paper.

STUDY AND METHODS

A study was designed to test the guide and validate the soil and site factors chosen. The Objectives of the study were to acquaint foresters involved in stand examination with the use of soil and site factors and collect data to check the guide recommendations against those of the forester using normal site classification procedures.

The portion of the Chattahoochee National Forest assigned to the Blue Ridge Province of the Appalachian Mountains made up the study area. Rugged mountains and ridges ranging from 1000 to 3400 feet with peaks up to 4000 feet are characteristic of the area. Geology consists of rocks such as granite, schists, quartzite, gneiss, mica-schists and metasedimentary rocks such as metagraywacke and phyllite. Soils range from loamy to clayey in texture and shallow to deep depending on slope, landform position and parent material.

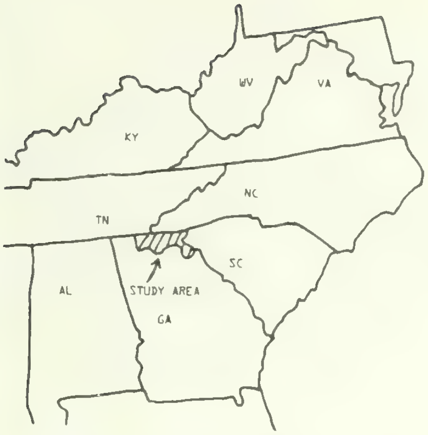

Figure 1.--Study area, Chattahoochee National Forest, northeast Georgia.

Soils are classified in the mesic Typic apludults and Typic Dystrochrepts families on sideslope and ridgetop positions; in Umbric ystrochrepts on colluvial positions and Fluventic Dystrochrepts on alluvial positions. Annual recipitation ranges from 52 inches on the west side of the Forest to a high of 80 inches at the ortheast corner near Clayton, GA.

Study data was collected at the sample plot ocations selected by the forester during stand xamination. A variable plot, defined by a BAF 0 prism, determined the plot size used for the lassification of forest and management type. t each plot the foresters entered information n aspect, landform position, topsoil depth, olum depth, elevation onto a small form. Each lot location was identified on a stand map to id in checking solum depth and landform osition classification assigned in the field.

Seven foresters participated in the study ith 241 plots examined being located across the ntire Forest. Sample plots were taken in the tands being examined as part of the normal ntry into areas being considered for treatment.

Data was summarized for each of the guide actors using a SAS program (Statistical nalysis System 1985). Summaries were made for ach of the soil/site factors in the guide with omparisons then made between the recommendaions of the guide and the foresters.

RESULTS AND DISCUSSION

andform Position

Agreement on management type based on andform position is shown in table 1. On idgetops agreement was high; both recommending ine.

Moving downslope the level of agreement declines particularly on the lower sideslopes. On a significant number of plots the guide recommends hardwood due to deeper, loamy and clayey soils and favorable moisture conditions. In contrast the foresters primarily recommended pine; probably influenced by the current stand condition. Although only 7 plots were sampled in alluvial positions the level of agreement was very low; the guide recommending hardwood, the foresters pine.

Table 1.-- Summary of agreement of forester and site suitability guide by landform.

Landform	Differ	Agree
	(percent)	
Alluvial	71	29
Colluvial	52	48
Sideslope	51	49
Ridgetop	29	71
All Plots	46	54

Aspects

The amount of agreement for aspect did not readily explain differences between the guide and the foresters. On sideslopes the percentage was about the same regardless of aspect. Again the guide generally considers the soil and site factors and favors hardwoods on most north facing positions and lower slopes of south facing aspects. The foresters again recommended pine over hardwood or mixed types.

Table 2.--Summary of agreement between site suitability guide and forester for aspect on sideslopes.

Aspect	Differ	Agree
	(percent)	
North-East	49	51
South-West	52	48

Surface Horizon Thickness

Data comparison based on surface horizon is inconclusive when comparing recommendations. This was expected due to the minimal experience of the foresters in sampling soil conditions for either soil depth or texture. A 12 inch auger was used for this procedure.

The data collected showed higher agreement for the 0-2 inch and 6 inch+ classes; lower for the 2-6 inch class. This category of data does not provide significant information to support a change in the guide. Table 3 summarizes this information.

Table 3.--Summary of agreement of prescribers with guide by soil surface thickness.

Surface	Differ	Agree
(inches)	(percent)	
0 to 2	41	59
2 to 6	61	39
6 +	42	58

Management Type

Table 4 summarizes the level of agreement for management type recommendations. The level of agreement on hardwood and pines was not significantly different; however for mixed types the disagreement level is high. This may be due in part to limited experience in classifying the mixed types and past policy limiting use of such types. This points out an excellent future use of the site suitability guide; identifying soil and site conditions favoring mixed management types.

Table 4.--Summary of agreement of prescribers with guide by management type.

Managment Type	Plots		Percent	
	Differ	Agree	Differ	Agree
	(number)			
Hardwood	33	44	43	57
Mixed	29	5	85	15
Pine	42	82	34	66

Of the 241 plots examined 124 plots or 52 percent were classified as pine mangement types. Hardwood management types were assigned to 80 plots or 33 percent and mixed types to only 37 plots or 15 percent. This assignment of plots favors the management of pine significantly over hardwood and mixed types. The deficiency in use of direct estimate of site potential is also evident; a large number of the stands are made up of low quality hardwood stems at present not displaying true site potential.

SUMMARY AND CONCLUSIONS

Estimating site potential by use of soil and site factors was found to be useful in recommending suitable management types on the Chattahoochee National Forest. In comparing the recommendations of the site suitability guide and foresters levels of agreement were about equal when considering landform position and topsoil depth. Agreement on aspects was not conclusive.

Agreement on management types identified the difficulty in relying on direct estimate of site potential using current stand conditions.. Use of the guide should improve classification of site productivity in such stands and also aid in identifying site conditions which favor different management types and species groups.

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Table 5.--Example of Site Suitability Guide, Chattahoochee NF, Georgia.

Landform Position	Aspect	Solum Depth (inches)	Topsoil Depth (inches)	Soil Texture	Recommended Mgmt Types	Hardwood Potential
Ridgetops						
	n/a	<20	>6	Clayey	Hardwood	Medium
				Loamy	Mixed	Medium
				Coarse	Pine	Low
			<2	All	Pine	Low
Upper Sideslopes						
	N-E	0-20	2-6	Clayey	Hardwood	Medium
				Loamy	Mixed	Medium
				Coarse	Pine	Low
		40 +	All	All	Hardwood	High
	S-W	0-20	All	All	Pine	Low
		20-40	All	All	Pine	Low
Middle Sideslopes						
	N-E	20-40	<2	Clayey	Hardwood	High
				Loamy	Hardwood	High
				Coarse	Mixed	Medium
			2-6	All	Hardwood	High
	S-W		2-6	Clayey	Mixed	Medium
				Loamy	Pine	Low
				Coarse	Pine	Low
Lower Sideslopes						
	N-E	<20	<2	Clayey	Hardwood	High
				Loamy	Hardwood	High
				Coarse	Mixed	Medium
		40 +	All	All	Hardwood	v.high

Explanation of Terminology

Solum Depth	Surface Depth (topsoil)	Soil Texture
0-20" Shallow	<2" Shallow	Clayey: clay, silty clay
20-40" Moderately deep	2-6" Moderately deep	Loamy: loam, silt loam
40"+ Deep	>6" Deep	Coarse: sandy, stony

Hardwood Site Potential	Recommended Management Type
Very High: site index 95+ for Yellow-Poplar	Hardwood
High: site index 75-95 for oaks	Hardwood
Medium: site index 65-75 for Oaks	Mixed or Pine, Ck Aspect
Low: site index <65 for oaks	Pine

Aspect N-E: Az. 330 to Az. 120
S-W: Az. 121 to Az. 329

Management Types See For. Serv. Hdbk 2409.21D for available types in R8

Harvesting-Soils

Moderator:

Wayne Haines

International Paper Company

SITE DISTURBANCE AND MACHINE PERFORMANCE FROM TREE-LENGTH SKIDDING WITH A RUBBER-TIRED SKIDDER[1]

J. A. Burger, K. J. Wimme, W. B. Stuart,
and T. A. Walbridge, Jr.[2]

Abstract.--To further the understanding of logging site disturbance, a study was conducted to assess skidder performance as a function of soil moisture content, tire size, and number of passes in the same track. Tire size and pass number had little effect on skidder speed and wheel slip at a soil moisture content of 18%. Under wet conditions, at 30% moisture, performance was unchanged during the first pass, but decreased precipitously with successive passes with both tire sizes. Site disturbance and rutting was less with the wide tires, but overall skidding performance did not improve significantly.

INTRODUCTION

In the southeastern United States, animals nd small tractors were used predominantly to kid logs up until the 1950's. During the 950's, crawler tractors and various attached mplements became popular because they could be sed for a variety of tasks including skidding, oad building, and landing and skid trail onstruction. The major drawback of the crawler ractor was its slow speed for skidding logs. he wheeled skidder was introduced in the early 960's and has proven to be very efficient. The evelopment of four-wheel drive, articulated eering, and axle oscillation, as well as the igher speeds and lower maintenance costs ompared with crawler tractors, have nsiderably increased the production capacities d desirability of these machines.

Although skidding performance and production has improved over the last three decades, site disturbance due to logging is still a significant problem. This is due primarily to the fact that the amount of site disturbance occurring during logging is more a function of site conditions such as terrain, soil type, soil moisture, amount of slash and litter, and stand type than it is a function of machine type, equipping of the machine, or its application. Changes that decrease site productivity, impair regeneration or other silvicultural activity, or adversely affect off-site ecosystems constitute site disturbance and is in no one's interest. The reality of the situation, however, is that wet sites and logging under wet conditions cannot always be avoided. Because of this, loggers, equipment designers, landowners, and silviculturists are working together to refine equipment and tire designs. Other efforts include modifying applications of the equipment to the job, characterizing and mapping site conditions, and coordinating harvest schedules with seasonal weather patterns and site conditions in order to eliminate adverse disturbance. Accordingly, this study was a cooperative effort among forest landowners, an equipment manufacturer, and university researchers to learn more about the constraints to log skidding under wet site conditions. Skidder performance and site disturbance were measured as a function of soil moisture, tire size, and the number of skidder passes in the same track.

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[1] Paper presented at Fifth Biennial Southern lvicultural Research Conference, Memphis, TN, vember 1-3, 1988.

[2] Associate Professor, School of Forestry and ldlife Resources, Virginia Polytechnic stitute and State University, Blacksburg, VA 061; Forester, Stone Container Corp. angeburg, SC, 29115; Associate Professor and ofessor, respectively, School of Forestry and ldlife Resources, Virginia Polytechnic stitute and State University, Blacksburg, VA 2061.

[3] Assistance with planning, executing, and sporting this study from Union Camp Corp., Fanklin Equipment Company, and Chesapeake Corp. personnel is gratefully acknowledged.

SITE DESCRIPTION AND PROCEDURES

The study was conducted as a controlled field trial on the Lower Coastal Plain in McIntosh County, Georgia. The study area was a 29-yr-old slash pine (Pinus elliotii Engelm.) plantation that had a site index of 66 ft (20 m) at age 25 and a basal area of 118 ft^2/acre (27.2 m^2/ha). The understory vegetation consisted of a 45% cover of gallberry (Ilex glabra (L.) A. Gray), 41% wiregrass (Aristida stricta Michanx.), and 14% other species. The litter layer averaged 21300 lb/acre (23870 kg/ha) on a dry weight basis. In October, 1985, prior to harvesting, the site was mapped and three replicate 800 by 60 ft (244 by 18 m) blocks were located within a 5 acre (2 ha) area on similar soil types. The soils included Bladen (clayey, mixed, thermic Typic Albaquults), Pooler (clayey, mixed, thermic, Typic Ochraquults), and Riceboro (clayey, mixed, thermic Aremic Paleaqults) series. These soils have shallow water tables during part of the year, an argillic horizon, and flat topography. The soil textures were loamy sand, sandy loam, and sandy clay in the A, E, and B_t horizons, respectively. A cross sectional profile of Block 3 is shown in fig. 1; it is representative of the other two blocks.

The site was harvested during May and June, 1986. Trees within the block boundaries were chain-saw felled and winched out of the blocks by a cable skidder, thus the study blocks were left in a non-trafficked condition. All brush was hand cut and left on site. Each of three blocks was divided into twenty-four 20 by 60 ft (6.1 by 18.3 m) skid zones with skidder access areas between four sets of six zones each (fig. 2). The corners of each skid zone were marked with stakes and paper plates for visibility. Two rut transect lines were located at 20 ft (6.1 m) intervals across each zone and soil sampling points were located at the intersection of the transect lines and the tracks (fig. 3).

The study design was a completely randomized block with the following treatments: two soil moisture contents at 18 and 30%; 1, 3, 9, and 27 skidder passes; and tire sizes of 28L-26, 67 x 34-25, and 73 x 44-32. Only the results of the two larger tires are reported here. All treatment combinations were randomly assigned to one of 24 skid zones in each block. The effects of the treatments on skidder speed, tire slip, and rutting are reported in this paper. Soil conditions were selected so that one level (18%, "moist trial") was near the optimal compactive moisture content, or proctor limit, and the other was just below the liquid limit, or the point at which soil begins to flow under pressure. These soil moisture conditions were obtained by applying one-half the treatment combinations in July (moist trial) and the other half in September (wet trial).

The 67 x 34-25 tire (hereafter referred to as the 34" (86 cm) tire) is a common and operationally-used tire, while the 73 x 44-32 (hereafter referred to as the 44" (112 cm) tire) is a wide flotation tire being considered for use under wet conditions by some operators.

A Franklin 170 grapple skidder was loaded with tree-length material and allowed to operate over stumps and articulate to successfully traverse the skid zones. It was operated at full throttle in second gear and restricted to

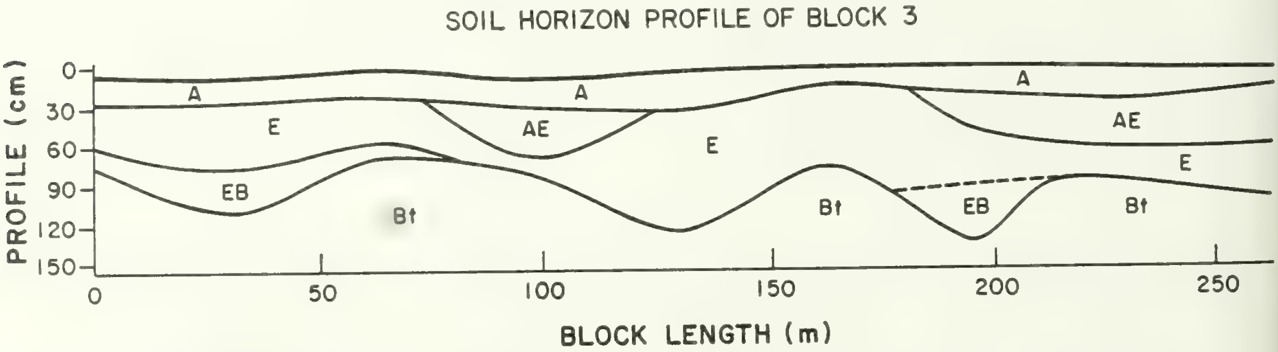


Figure 1.--Representation of the soil profile across study block 3. Soil profiles of the other blocks were similar.

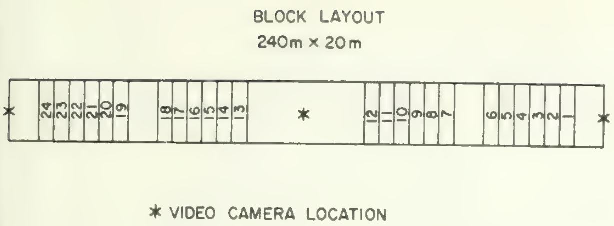


Figure 2.--Block layout showing skid zones, access lanes and video-camera locations.

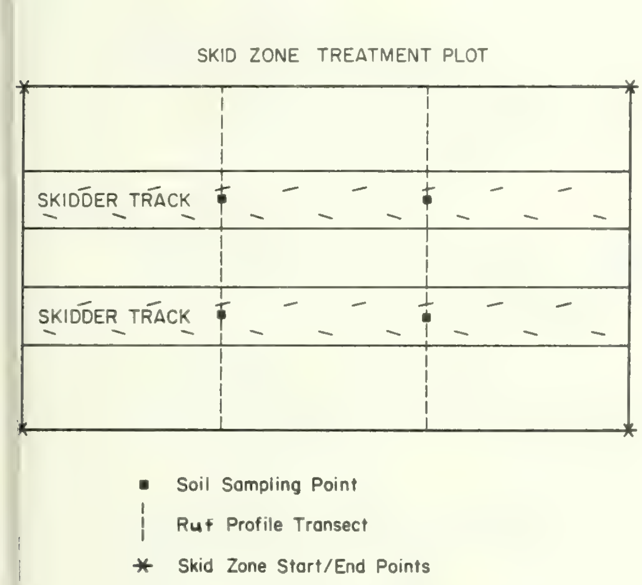


Figure 3.--Skid zone layout showing locations of rut transects and soil sampling points.

the same tire paths and travel direction on multiple-pass treatments. The log load was maintained at 6800 lb (3084 kg) throughout the execution of the treatments. Skidder operation through each skid zone was videotaped from stationary camera locations; the tape was used to determine wheel slip and skidder speed. Revolutions of all four wheels within the 60 ft (18.3 m) zone were counted.

Rut profiles were drawn (plotted using SAS/GRAPH, (SAS Institute, Inc. 1985)) from two pre- and post-disturbance transects across each kid zone (fig. 4). A steel tape was held taut t a known elevation above the ground. A measuring stick was used to define the ndisturbed and disturbed topography across the kid zone relative to the control tape. isturbance was classified as churn, compaction, ut, and total disturbance, and delineated by artioning the cross sectional area of each sing computerized planimetry (fig. 4).

Analysis of variance procedures were used to scertain differences among treatment ombinations. To ensure normal distributions of he data, the arcsine transformation of the slip ata, and the square root transformation of isturbance data were used in the analyses.

RESULTS AND DISCUSSION

Skidder speed and tire slip are shown as a function of all three factors simultaneously in figures 5 and 6. At 18% soil moisture, there was no significant difference in skidder speed when mounted with the 34" tires versus the 44" tires (fig. 5). Speed did not change with number of passes in the same track; through 27 passes it averaged 407 ft/min(130 m/min) when mounted with the 34" tires, and 360 ft/min (115 m/min) when mounted with the 44" tires.

At 30% soil moisture content, skidder speed during the first pass mounted with either tire size was the same as the speed attained at the lower soil moisture content (fig. 5). By the third pass, however, the speed was only one half that attained during the first pass. Again there was no difference between skidder performance as a function of tire size during the third pass under wet conditions. The primary performance difference between tire sizes was the total number of passes attainable before bogging; eight passes in the same track were possible with the 44" tires, while only half as many were possible with the 34" tires.

Skidder speed was a direct function of tire slip; this is evident by comparing speed and slip data between the graphs (figs. 5 and 6) as a function of the various treatment combinations. Trends and differences in the tire slip data were virtually the same as those for skidder speed.

There was little measurable soil and site disturbance due to skidder trafficking when the soil moisture content was at 18%. The litter layer was displaced by the log load after several passes, but no significant soil churning or rutting due to skidder traffic occurred. At 30% soil moisture content, significant differences in disturbance occurred as a function of both tire size and number of passes (table 1). After one pass there was a larger amount of surface churn caused by the wider tire, but after three passes, the narrower tire created more disturbance, churn, and larger ruts than the wider tire. The transect-area disturbance created by the narrower tire was roughly twice that caused by the wider tire (table 1). Typical rut profiles contrasting the effect of the two tire sizes after 3 passes at 30% soil moisture content is depicted in figure 4.

An estimate of soil compaction at the skid zone transects was made by subtracting the cross sectional area of soil displaced above the control line from the cross sectional area of the rut (table 1). A positive value suggests soil compaction, while a negative value indicates net soil loosening, or the creation of additional macro pore space. After either one or three passes, the narrower tire caused net compaction while the wider tire caused net loosening of the disturbed soil (table 1).

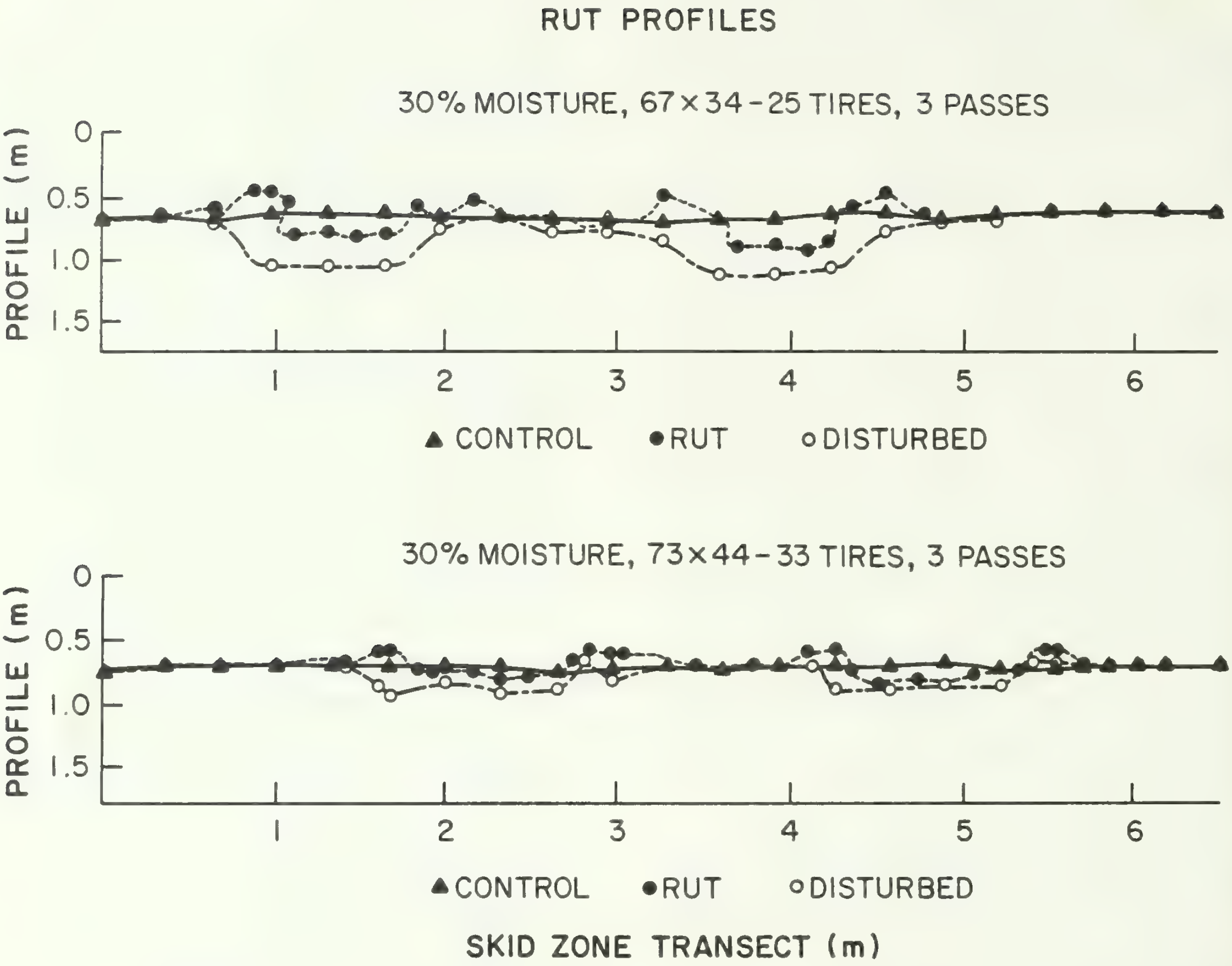


Figure 4.--Example of a skid zone profile comparing disturbance created by two different tire sizes.

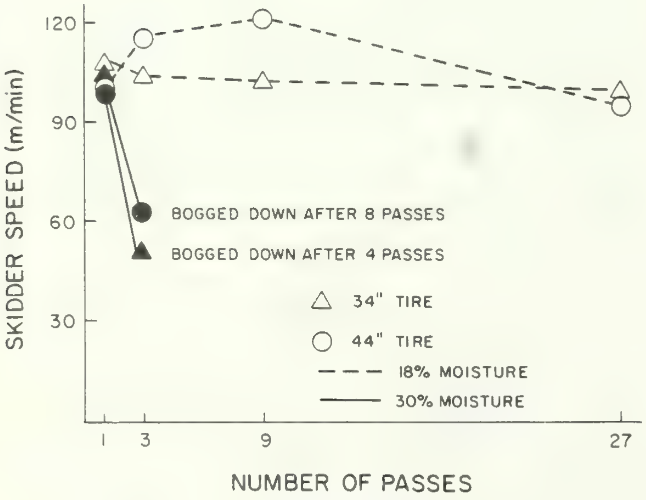


Figure 5.--Skidder speed as a function of soil moisture content, tire size, and number of passes.

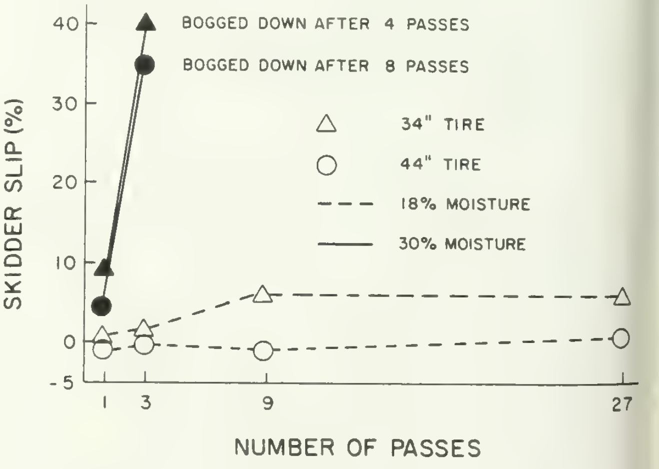
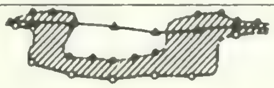
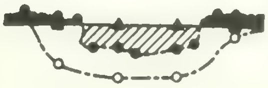
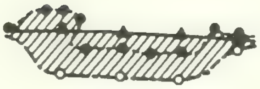
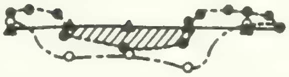


Figure 6.--Tire slip as a function of soil moisture content, tire size, and number of passes.

Table 1.--A comparison of four types of site disturbance as a function of tire size and number of skidder passes.

WET LOGGING DISTURBANCE		Tire Size	Number of passes	
			1	3
			------m^2-------	
CHURN		34"	0.17a[1]	0.88a
		44"	0.47b	0.56b
COMPACTION		34"	0.05a	0.05a
		44"	-0.04b	-0.08b
DISTURBANCE		34"	0.21a	0.93b
		44"	0.43a	0.47b
RUT		34"	0.11a	0.22a
		44"	0.08a	0.13b

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[1] Different letters indicate a significant difference (a = 0.05) in response to tire size within a disturbance class.

The occurrence and degree of adverse soil and site disturbance, and the performance of rubber-tired skidders on these and related soils, is clearly a function of soil moisture content. Soil disturbance and rutting can be avoided by delaying harvests until soils are fully drained. Scheduling annual harvests of multiple tracts so that the most poorly drained sites are logged during the driest season of the year may be a logical first step for avoiding damage. However, given the necessity of logging a poorly drained or wet site, the results of this study show that the judicious use of certain traffic patterns, namely spreading the traffic as widely as possible on the site, can minimize or eliminate site disturbance while maintaining a reasonable level of skidding performance. Even at this very high soil moisture content, at least one pass at normal speeds, even with the 34" tires, was possible while causing little site disturbance. Multiple passes in the same track with either tire size, however, quickly resulted in reduced performance and soil disturbance. This failure in carrying capacity is most likely due to an increase in volumetric soil moisture content as pore space decreases, resulting in reduced soil strength as the moisture content approaches the liquid limit.

Differences in performance (skidder speed and tire slip) observed in this study do not warrant the extra expense of wide tires; however, the wide tires may be justified based on reduced site disturbance. Although the wider tires doubled the number of passes achievable in the same track before bogging, this is hardly justification for their use, because the amount of soil disturbance becomes unacceptable well before the point of bogging down. Careful harvest scheduling and experienced skidder operators who understand the subtle interactions between machine dynamics and soil properties appear to be the best deterrents of inefficiency and site damage when logging wet or poorly drained sites with high water tables.

LITERATURE CITED

SAS Institute, Inc. 1985. SAS/GRAPH Version 5. SAS Institute Inc., Box 8000, Cary, NC 27511.

EFFECTS OF CURRENT HARVESTING PRACTICES ON THE PHYSICAL PROPERTIES OF A LOESSAL SOIL IN WEST-CENTRAL MISSISSIPPI[1]

J. M. Rachal and B. L. Karr[2]

Abstract.--Bulk density and pore space distribution were characterized on four sites in the Upper Thick Loess soil resource area of west-central Mississippi before and after operational harvesting under wet and dry conditions on Memphis silt loam. Following harvesting, skidder disturbance was classified into four categories according to rut depth: undisturbed, tertiary (0-1.5 inches), secondary (1.6-3.0 inches), and primary (>3.1 inches) skid trails. Soils were sampled by disturbance class at 0-3, 3-6, and 6-9 inch depths. Soil movement along skid trails was also monitored. Soil physical properties were impacted to a greater degree on areas logged under wet conditions than areas logged when dry. Bulk density was increased a total of 23.3% and 17.6% for wet and dry areas, respectively. Redistribution of pore space was much greater on wet logged areas than areas logged when dry. Rutting depth was significantly correlated to soil movement indicating increased gullying (soil loss) as rut depth increased. When possible, harvesting operations on this soil type should be planned to occur during dry conditions as wet weather skidding can cause negative alterations in physical properties and greatly increase likelihood of soil loss, both of which can reduce site productivity.

INTRODUCTION

Forest soils are susceptible to physical lterations during harvesting that may reduce site roductivity. The weight and movement of skidders nd other mechanical equipment can compact, mix, nd redistribute surface soils. Although the usceptibility of soils to alteration varies greatly, in the southeastern United States ncreases in bulk density of 10 percent in econdary skid trails and 50 percent or more on rimary skid trails and loading decks have been eported (Hatchell and others 1970, Lockaby and idrine 1984, Karr and others 1987). Compacted oils have less total porosity with most of the oss occurring in macropore space. Karr and thers (1987) reported that a feller buncher rossing a bedded silty clay loam soil during a thinning operation reduced macroporosity by 50 percent. Losses in macroporosity as high as 65 percent were reported in a study of Piedmont soils (Gent and others 1984). Decreased porosity and increased bulk density resulting from soil compaction reduces root development, increases plant-water stresses, and increases likelihood of attack by organisms such as the southern pine beetle (Moehring 1970, Froehlich 1979, Nebeker and others 1985). Reduced growth rates in compacted areas have been associated with problems in aeration, moisture and nitrogen relationships, and mechanical impedance. Jamison (1956) suggested that roots in compacted soils are unable to develop sufficiently to utilize moisture even when it is readily available.

In Mississippi, a band of loessal soils exists on the east side of the Delta soil resource area and extends from Tennessee on the north to Louisiana on the south. This area was once an embayment of the Gulf of Mexico, and the soils were derived from deposits of sand, clay, and gravel. During the Pleistocene Age, wind-blown materials (loess) were deposited over the existing landscape. This mantle is thickest along its western edge and decreases in depth towards the east until the underlying coastal plain material is exposed. Where the loess is thick, the entire profile is derived from loess as in the Memphis and Loring soils.

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[1] Paper presented at the Fifth Biennial Southern ilvicultural Research Conference, Memphis, ennessee, November 1-3, 1988. Contribution No. S7060 of the Mississippi Agricultural and orestry Experiment Station.

[2] Research Assistant I and Associate Professor, epartment of Forestry, Mississippi State niversity, Mississippi State, MS 39762.

When disturbed by cultivation, fire, logging, etc. loessal soils tend to "seal over" under the impact of rainfall, thereby limiting infiltration and increasing surface runoff (USDA 1988). Therefore, these soils are very fragile (especially when found on steep slopes) and have been severely gullied from poor farming practices in the past. In 1948, the Yazoo-Little Tallahatchie (Y-LT) Flood Prevention Project was initiated to rehabilitate these eroding soils. Over 621,000 acres were planted to pine by 1982 (USDA 1988). Many of these plantations are now being thinned or clearcut causing much concern among forest managers and conservationists that unchecked soil loss will begin anew. This study was initiated to monitor soil movement following equipment trafficking and to characterize changes in selected physical properties of a loessal soil during wet and dry weather logging.

METHODS

The study sites are located in the Upper Thick Loess soil resource area of west-central Mississippi (Pettry 1977). Topography is rolling to steeply dissected hills with caps of loess and side slopes frequently eroded exposing underlying Upper Coastal Plain materials. The result is a complex of fragile, erosive soils.

Four harvesting sites were selected across the Upper Thick Loess Region in Holmes, Carrol, and Tallahatchie Counties, Mississippi, and were chosen as representative of dry and wet weather logging on Memphis silt loam, a soil derived entirely from loess. Sites were operationally harvested over a period of 3 years (1986-1988) by local logging contractors using standard practices. Soil moisture was closely monitored during logging, and each operation was classified as occurring under wet or dry conditions. Soils were considered dry if the gravimetric content moisture averaged less than 10 percent during the operation and wet if greater than 10 percent.

Prior to logging, soil samples were taken and bulk density and porosity determined to characterize pretreatment conditions at each location. Following the harvesting operation, disturbance of skidders was classified into four classes according to rutting depth. Soils were resampled by disturbance class and bulk density and porosity determined. Trail classes were: no disturbance, tertiary = 0-1.5 inches, secondary = 1.6-3.0 inches, primary = greater than 3.1 inches. Depth of rut was measured from original ground line to center of tire track.

Porosity and bulk density determinations were obtained from 3 in. by 3 in. undisturbed cores using the slide-hammer method (Blake 1965). Cores were taken at 0-3, 3-6, and 6-9 inch depths. Total porosity, microporosity, and macroporosity were determined by the procedure described by Cassel (1974). Oven-dry weight of soil cores was used to express bulk density as weight/unit volume (g/cc).

Soil movement (erosion and deposition) along primary, secondary, and tertiary skid trails and slope gradient of each trail were measured on fifteen skid trails in Tallahatchie County. Measurements were made by driving 3 foot sections of rebar into ruts leaving a standard length above and below ground (fig. 1). Three rebar sections were installed at each of three slope positions; upper, middle, and lower; for a total of nine rebar sections per trail. Length of rebar remaining above ground was measured and the difference between this measurement and the standard at installation represented soil movement. Soil deposition was indicated by a positive difference, and a negative difference indicated soil loss or erosion.

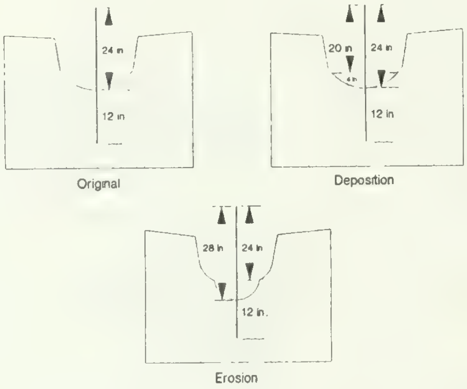

Figure 1.--Cross section of a rut showing technique used for measuring soil movement

RESULTS AND DISCUSSION

Bulk Density

Across all sites, analysis of variance for bulk density indicated a highly significant ($P < .01$) effect due to skidder traffic. At all sampling depths, skidder trafficking caused a significant increase in bulk density compared to undisturbed areas (table 1). Across all trafficking levels, bulk density was increased an average of 12.1 percent for the surface nine inches. Campbell et al. (1973) found similar results for loamy soils in Georgia, reporting an average increase of 13.8 percent.

Bulk density response to increasing levels of equipment traffic generally follows a pattern established by Hatchell (1970) and others which shows a rapid increase in bulk density with the first few trafficking trips and little or no increase with additional trips. In the surface three inches, bulk density was increased 12.6 percent on tertiary trails compared to the control. Comparing tertiary to secondary trails and secondary to primary trails this increase was 3.7 percent and 5.7 percent, respectively, Table 1.--Mean bulk density of Memphis silt loam measured at three depths following trafficking of a rubber-tired skidder.

Trail Classification	Bulk Density 0"-3"	3"-6"	6"-9"
	------------g/cc-------------		
Undisturbed	1.19 c1/	1.37 c	1.39 c
Tertiary	1.35 b	1.44 b	1.48 b
Secondary	1.39 b	1.50 a	1.51 a
Primary	1.48 a	1.53 a	1.55 a

1/Means within columns not followed by the same letter are significantly different (P = .05) according to Duncan's NMR test.

reflecting the previously described pattern. Compared to undisturbed controls, bulk densities were increased twice as much on primary trails compared to tertiary trails, i.e. an increase of 24.4 percent compared to 12.6 percent.

The degree to which a soil can be compacted is highly dependent on soil moisture content, among other things (Omi 1985). Changes in bulk density following harvesting during wet and dry conditions were measured for Memphis silt loam (table 2).

Table 2.--Mean bulk density for the surface three inches of Memphis silt loam following wet and dry weather trafficking.

Trail Classification	Bulk Density Wet	Dry
	-----------g/cc------------	
o disturbance	1.20 b1/	1.19 c
ertiary	1.35 a*	1.24 cb
econdary	1.40 a	1.32 ab
rimary	1.48 a	1.40 a

1/Within-column bulk densities followed by the ame letter are not significantly different P = .05), and within-row bulk densities which re significantly different (P = .05) are elineated by an asterisk.

Bulk density was consistently higher following et weather trafficking compared to dry weather trafficking, but this increase was significant on e tertiary trails only. Bulk density was creased a total of 23.3 percent and 17.6 percent or the Memphis soil logged under wet and dry onditions, respectively.

These results suggest a direct relationship between soil wetness and the maximum attainable bulk density for a given compactive effort. This is true for moisture contents below a certain level. Above this level, the maximum attainable bulk density is decreased by increased soil wetness because water-filled pores prevent closer packing of the soil particles.

Porosity

One of the most important consequences of forest soil compaction is the reduction in air porosity. Reduced porosity decreases aeration and increases mechanical resistance to root growth. Rainfall infiltration is reduced thereby increasing surface runoff and reducing percolation of water needed for tree growth. Of equal importance is the change in pore size distribution as soils are compacted. Previous investigators have shown that most of the loss of pore space occurs in the macropores, while the micropore space increases or remains relatively unchanged (Greacen and Sands 1980, Adams 1983). In the present study, the general trends in porosity following wet and dry weather skidding are similar to those just described.

Soil moisture content at the time of trafficking has a major influence on reduction and redistribution of pore space as soils are compacted. Dry soils are more resistant to changes in pore size distribution and this resistance is reduced as soil moisture content increases (Eavis 1972).

Total and macro pore space were significantly reduced by wet and dry weather trafficking of Memphis silt loam (fig. 2). Absolute macroporosity was reduced slightly more under wet conditions compared to dry conditions, i.e. 11.1% compared to 10.5%. On wet logged sites, microporosity was significantly increased by trafficking, but remained unchanged on areas logged during dry conditions. Macroporosity comprised 10.9% and 14.4% of the total pore space on areas compacted during wet and dry conditions, respectively.

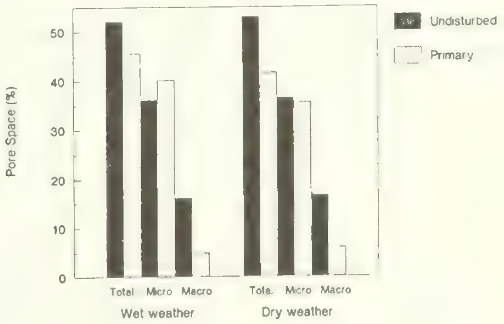

Figure 2.--Distribution of pore space following wet and dry weather logging of Memphis silt loam.

Such changes in pore size distribution can have an important effect on the moisture-holding characteristics of a soil and therefore effect the amount of moisture available for plant growth. This is especially true at the lower suctions (0-1 bar of suction) where compaction tends to have its greatest affect (Eavis 1972). The effect of compaction is to decrease the volume of the large interaggregate pores thereby reducing the amount of water yielded at low suctions. Because macroporosity was reduced to a greater extent by wet weather trafficking, it may be hypothesized that aeration-moisture relationships important to root growth will be impacted to a greater extent on these areas.

Effects on Seedling Growth

The degree to which a soil can be compacted before reaching its growth-limiting bulk density (GLBD), i.e. the bulk density where resistance to root penetration is such that root growth is essentially stopped, is highly dependent on soil texture (Daddow and Warrington 1983). Fine-textured soils have lower GLBD´s than coarse-textured soils because at similar bulk densities the former has smaller pores and a higher penetration resistance than the latter.

In 1983, Daddow and Warrington developed a relationship between soil texture and the observed growth-limiting bulk density for a wide range of agricultural crops and tree species. This relationship was plotted on a textural triangle to locate the growth-limiting isodensity lines. From this triangle, the GLBD´s for the soil interest was estimated: 1.40 g/cc to 1.45 g/cc for Memphis silt loam.

At the two highest levels of trafficking on a wet Memphis soil, the measured bulk densities exceeded the GLBD, and under dry conditions the GLBD was attained on primary trails (table 2). This indicates the possibility for losses in productivity following trafficking on Memphis silt loam, especially during wet conditions. Root growth is slowed by compaction long before the GLBD is reached, therefore, high-use trails on dry Memphis and all levels of compaction on wet Memphis soils produced bulk densities which will probably negatively impact seedling growth. It seems apparent that Memphis silt loam is a very fragile soil in terms of losses in productivity due to harvest trafficking, and this sensitivity increases as soil moisture at skidding increases.

Soil Movement Along Skid Trails

In addition to changes in physical properties, soil movement, i.e. erosion and deposition, can be an important component of the overall effect of skidder trafficking on site productivity. In general, soil movement increased as rut depth increased (fig. 3). Analysis of variance resulted in a significant ($P < .05$) effect due to rutting depth at all slope positions for Memphis silt

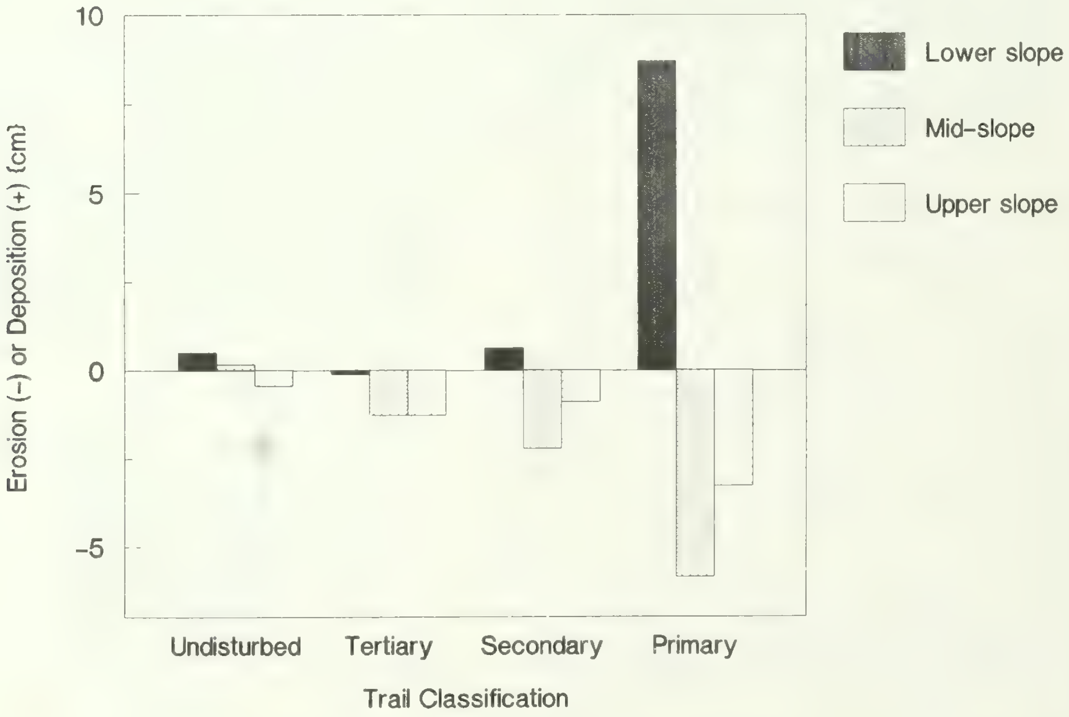

Figure 3.--Soil movement along skid trails on Memphis silt loam six months after logging.

loam. The average slope gradient for all trails used in the analysis was 15.9%. This can be broken down by trail class as follows: 15.0% on undisturbed areas, 18.3% on tertiary trails, 15.0% on secondary trails, and 15.3% on primary trails. Correlation coefficients between rut depth and soil movement for each slope position are as follows: -0.56, -0.59, and 0.82 for the upper, middle, and lower slopes, respectively. All coefficients are significant at P = .01. Rut depth was negatively correlated to soil movement on mid- and upper slopes indicating increased gullying (soil loss) as rut depth increased. Strong positive correlation was noted on the lower slopes indicating increased deposition as rut depth increased.

Maximum gullying was noted on the mid-slope of primary trails on Memphis silt loam where 5.8 cm of soil was lost. Lower-slope soil deposition was significant with 8.6 cm being accumulated.

These results again reflect the fragile nature of Memphis silt loam. This soil seems to be highly unstable when disturbed and therefore susceptible to gullying and sheet erosion. Personal observation leads these authors to believe that even low-use trails can suffer significant soil loss if not quickly revegetated or otherwise stabilized.

CONCLUSIONS

Due to the steep slopes and fragile nature of the soils found in the loessal hills of west-central Mississippi, poor harvesting practices pose a serious threat to the productivity of this region. Poorly planned skid trails and loading decks can unnecessarily increase the area which is rutted and compacted causing needless losses in productivity. Harvesting during wet conditions seems to magnify the problem.

To help mitigate productivity losses, trails from prior entrances should be used if possible and new trails should be planned so that disturbance is concentrated on the fewest trails possible. When possible, harvesting operations should be planned to occur during dry conditions as wet weather skidding can cause significant negative alterations in soil physical properties and greatly increase the likelihood of soil loss. On deeply rutted areas, primary and secondary trails should be stabilized by installing water bars, establishing vegetation (such as grasses), or some other method especially if trails are oriented perpendicular to the contours. Lack of stabilization will likely result in gullying which can reduce productivity for years to come.

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INFLUENCE OF TRAFFICKING AND SOIL MOISTURE ON BULK DENSITY AND POROSITY ON SMITHDALE SANDY LOAM IN NORTH-CENTRAL MISSISSIPPI[1]

Yanfei Guo and Bob L. Karr[2]

Abstract.--Trafficking treatments of 0, 1, 3, 6, and 12 turns (passes) of a loaded skidder were applied during dry, medium, and wet soil conditions on Smithdale sandy loam in north-central Mississippi. Soils were sampled before and after treatment for bulk density, total porosity, macroporosity, and microporosity. Bulk density increased with increased number of skidder turns; however, most of the increase occurred in the first three turns and reached a maximum within six turns. Total porosity decreased with increased trafficking. Most of the loss was in macroporosity development. Results imply that trafficking should be restricted to a few heavily used trails rather than many trails with two or three turns.

INTRODUCTION

Although the wide application of mechanical harvesting greatly increases the efficiency of forest harvest and management, it may cause unfavorable soil conditions for forest regeneration and production. Soil compaction, due to the heavy weight of these machines, collapses soil structure, reducing soil air volume and increasing soil bulk density. As a result, tree root development meets more resistance and soil eration may be inadequate, reducing tree growth n compacted soils. Studies have revealed that indeed soil compaction does reduce seedling survival and tree growth in many cases (Foil and thers 1967, Hatchell 1970, Froehlich 1980, 1986).

The extent and degree of soil compaction upon soils vary with soil type and soil moisture (Foil 967, Howard 1981). Some fragile soils are easily isturbed and/or eroded and sensitive to echanical harvesting. Increasing soil moisture lso influences soil compaction (Moehring and awls 1970). For a given force or compactive ffort, soil density increases with increasing soil moisture until optimal[3] moisture content is reached after which soil density decreases with increasing water content (Means and Parcher 1963). To reduce soil damage, logging schedules should be predicted for an individual soil type in an allowable soil moisture range. However, few soil-equipment interaction studies have been made in the southern United States. The objective of this study, therefore, was to determine the changes in compaction of a fragile soil over a range of soil moisture conditions in north-central Mississippi.

METHOD

The study was located within the Upper Coastal Plain physiological province of north-central Mississippi in Montgomery County. The site is dominated by Smithdale sandy loam soil (Taxonomic Class: Fine-loamy, siliceous, thermic Typic Hapludults) which is located on ridge tops, and slopes. The thickness of the sandy loam soil gradually decreases from the upper slope to lower slope. Sandy loam of 20 to 100 cm in depth covers the sandy clay loam and occurs on 10 to 15 percent slopes.

A randomized complete block design with three replications per treatment was applied to test the effect of soil compaction on soil bulk density and porosity. The treatments were:

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[1] Paper presented at Fifth Biennial Southern ilvicultural Research Conference, Memphis, TN, ovember 1-3, 1988. Contribution No. PS7063 of he Mississippi Agricultural and Forestry xperiment Station.

[2] Graduate Research Assistant and Associate rofessor, Department of Forestry, Mississippi ate University.

[3] Optimal moisture is the moisture content at which soil reaches its maximum bulk density at certain amount of compaction effort.

1. Soil moisture, three levels: dry, medium, and wet. The soil moisture content for these three levels were 2.9, 14.2, and 16.4 percent averaged for the studied depth (0 to 24 cm).

2. Number of turns of skidder, five levels: control (non-treated), 1, 3, 6, and 12 turns.[4]

Samples for bulk density and porosity were collected at five locations in each plot before treatments were applied and at three locations in skid trails and at three locations between the skid trails after treatments were applied. At each sample location, samples were taken at three depths (0 to 8, 8 to 15, and 15 to 24 cm). Soil bulk density and porosity were determined by following the method described by Cassel (1974).

The data were analyzed by analysis of variance and covariance analysis. Covariance analysis was used to adjust the final differences among the plots.

RESULTS AND DISCUSSION

Soil moisture increased the susceptibility of soil to compaction at each of the three depths examined (fig. 1). Within 8 cm of the surface, bulk density of the control was 1.15 g/cc and average bulk density of all trafficking treatments during dry conditions was 1.40 g/cc or an increase of 22[5] percent. Under medium and wet conditions at this depth, bulk density increased to 1.53 g/cc, an increase 32 percent. Lack of resolution between medium and wet soil moisture conditions was due to the small difference of 2.2 percent between the two soil moisture classes. A weaker trend of soil moisture influences continued through the 24 cm depth. Bulk densities increased 8 and 22 percent for dry and medium or wet soils at 8 to 15 cm depth. Although the relative changes differed little between treated and untreated plots at depth of 15 to 24 cm, it increased almost 15 percent when soils were wet. The conclusion is that soil moisture influences the extent of physical disturbance in soils from skidder traffic.

The number of turns by the skidder also influenced bulk density and interacted with soil moisture to produce patterns of disturbance that are of particular significance to management (fig. 2). One turn of the skidder averaged increasing bulk density of surface soil from 1.15 to 1.33 g/cc (16 percent). This increase was 67 percent of the total change. Bulk density went to 1.41 g/cc with 3 turns and increased only slightly with 12 turns. Increasing soil moisture caused about 33 percent increases in bulk density at the same depth. At deeper depths bulk density increased only slightly in dry soils and very similarly to that of surface soil during wet conditions (fig. 2).

Soil moisture at time of trafficking greatly influences the degree and extent of soil compaction. Under dry condition, most effects of trafficking were not substantial and concentrated in the surface 8 cm of soil. Dry soil, due to its higher resistance to the exterior compression, can withstand heavier trafficking without large changes in bulk density and porosity than wet soil (Greacen and Sands 1980, Howard and others 1981). In this study greatest bulk density in dry soil was 1.40 g/cc, compared to a high of 1.65 g/cc in medium and wet soils. The resistance of dry soil to the trafficking was about 18 percent greater than that of medium and wet soils. Froehlich and McNabb (1984) described the relationship between moisture content and bulk density for four soils from the west slopes of the Sierra Nevada Mountains of northern California. They found that a dry sandy loam soil at moisture content of 3 to 4 percent under compaction had bulk density of about 1.36 g/cc, compared to bulk density of 1.57 g/cc at moisture content of 20 percent. The resistance to compression of the dry soil was about 15.4 percent more than that of the wet soil. The difference between medium and wet soils in our study was probably due to the small difference (2.2 percent) in moisture content. This slight increase in moisture content may not decrease the soil strength or change the soil physical property. A standard Proctor curve made by Froehlich (1980) for a sandy loam soil shows that maximum bulk density occurred at 13 percent moisture content. The maximum bulk density for sandy loam soil mentioned in Froehlich and McNabb (1984) study occurred at 20 percent moisture content. Various optimal moisture contents for different soils have been developed (Howard and others 1981, Sidle and Drlica 1981), and the optimal moisture content for a given soil is likely a function of soil types. The optimal moisture content for sandy loam soil is relatively low. In our study, the optimal moisture content may be around 14 percent and a slight change of moisture content would not significantly change soil density as indicated by our results.

Although an increase in soil water of 2.2 percent from medium to wet soil conditions did not affect compaction, soil trafficability was noticeably decreased. Traction was markedly reduced for the skidder.

The relationship between number of skidder turns and the degree of compaction was not linear. In our case, one-turn trafficking made a large amount of compaction, generally more than 50 percent of the total, and three-turn trafficking accounted for the 90 percent or more of the total compaction. The results correspond roughly with the works of the other researchers that the first few passes are most critical to the soil compaction. Hatchell and others (1970) found a very sharp increase in bulk density after one or two trips and a gradual increase with additional trips on Atlantic Coastal Plain soils. Froehlich and others (1980) similarly reported that about 60

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[4] A turn was one down slope pass of an unloaded skidder through a plot and a return up slope pass pulling three logs weighing 4,780 Kg.

[5] Significant at 0.01 level.

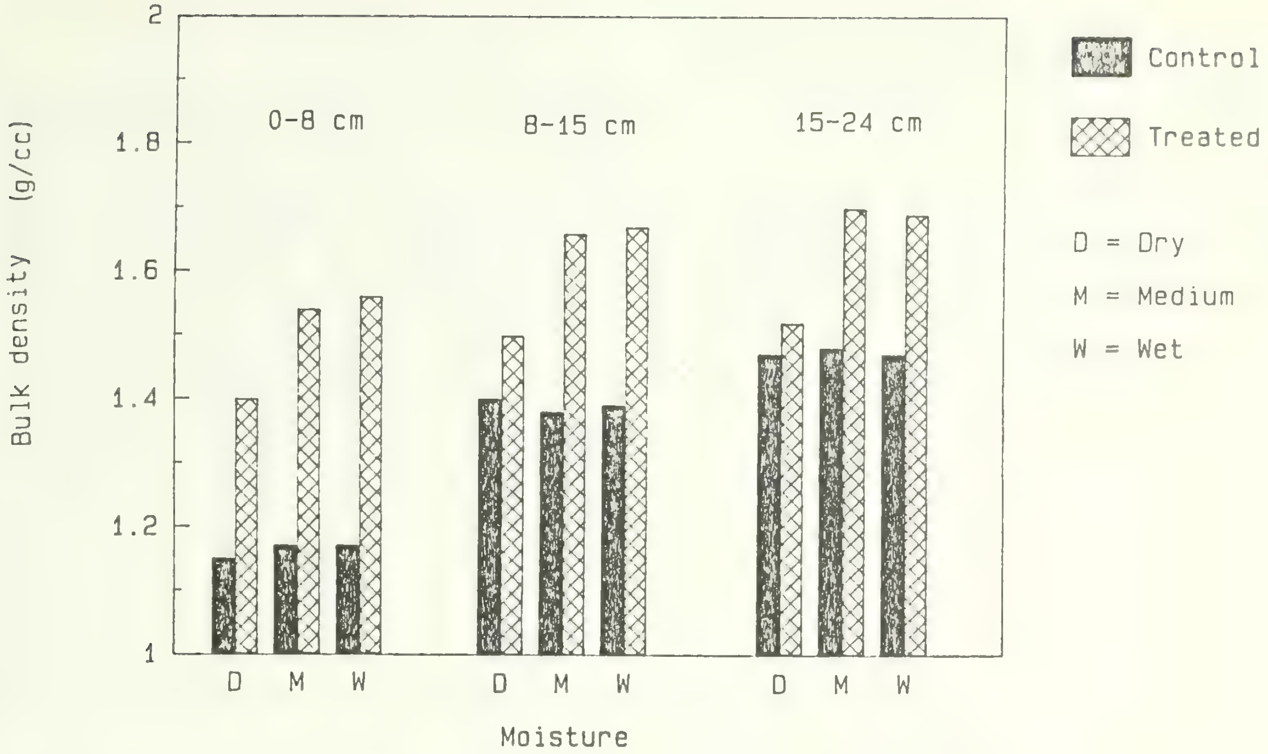

Figure 1. The changes in bulk density associated with soil moisture and depth

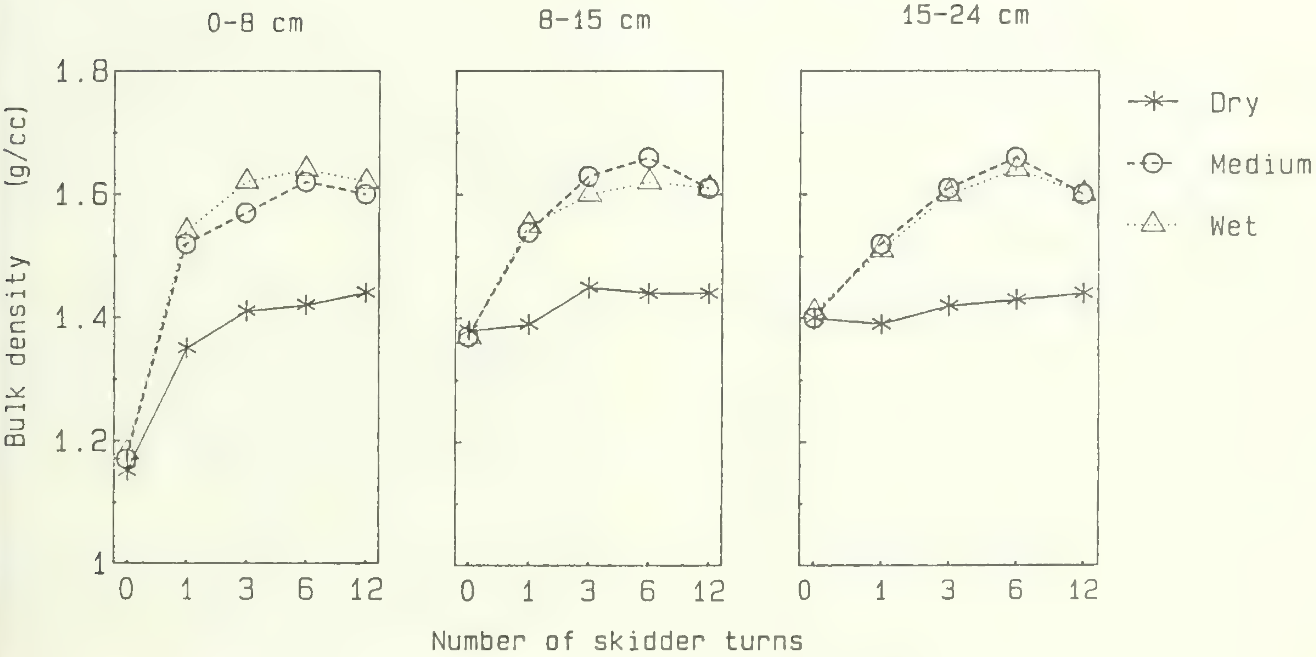

Figure 2. The changes in bulk density associated with number of skidder turns, soil moisture and depth

rcent of the change in soil density after 20 tips was reached by the sixth trip. Lenhard (986) reported that maximum bulk density was reached after only four trips for a forest soil developed from volcanic ash. However, he found that there were no differences between 0 (control), 1 and 2 trips. An inference then can be drawn that logging machines should limit themselves on the ruts they have made so that the affected areas can be restricted to the minimum, as suggested by Hatchell (1970) and Froehlich (1980).

Porosity decreased as number of skidder turns and moisture increased. However, the change was not as great at greater depths of soil. This influence is more clearly expressed if the effect of number of turns is averaged by soil moisture class as in table 1. Porosity decreased 19, 27, and 22 percent in the surface 8 cm for dry, medium, and wet soil moisture conditions respectively. The change was progressively less at deeper depths with much smaller decrease in dry soil (table 1).

Table 1.--Porosity changes averaged over number of turns associated with moisture and depth.

Moisture	Depth	PBC	PAC	A.D.	R.D.
	cm	Percent			
	0-8	50.7	41.3**	-9.4	18.5
Dry	8-15	42.2	38.3*	-3.9	9.2
	15-24	39.9	37.2	-2.2	6.8
	0-8	49.9	36.3**	-13.6	27.3
Medium	8-15	42.9	32.1**	-10.8	25.2
	15-24	40.1	31.6**	-8.5	21.2
	0-8	50.3	39.2**	-11.1	22.0
Wet	8-15	44.8	32.3**	-12.5	27.9
	15-24	40.5	32.7**	-7.8	19.3

PBC = Porosity before treatment
PAC = Porosity after treatment
A.D. = Actual decrease
R.D. = Relative decrease from the original porosity
** = significantly different at 0.01 level
* = significantly different at 0.05 level

Loss of macroporosity accounted for most of the change in porosity. In dry soil the surface soil lost 44 percent of its macroporosity but at deeper depths little change occurred. However, in medium to wet soil, macroporosity was reduced by more than half. The small increase (2.2 percent) from medium to wet moisture made little difference at the surface but at deeper depths loss of macroporosity was directly related to soil moisture. The implication for management is that the wetter the soil the greater the depth to which macroporosity would be altered (fig. 3).

Increasing the number of skidder turns also decreased macroporosity. However, as with bulk density, most of the change occurred within 3 turns (fig. 4). For surface soil macroporosity dropped from 25 percent to 19 percent with one turn and 16 percent with 12 turns on dry soil. When wet, it fell to 14 percent with one turn and 10 percent with 12 turns.

Microporosity was little affected by skidder trafficking. It varied only 4 percent from treatment to treatment, and showed no trend.

Macroporosity largely determines potential soil aeration (Froehlich 1980). Steinbrenner (1955), van der Weert (1974), Greacen and Sands (1980) have demonstrated the reduction in macroporosity following mechanical logging. They also demonstrated that total porosity was reduced due to the reduction of macroporosity and the proportion of microporosity increased because of the decrease of macroporosity. Froehlich (1980) reported, however, that logging vehicle traffic had little effect on total porosity of the surface soils in northern California, but the proportion of microporosity increased at the expense of macroporosity. We found that total porosity was greatly reduced in the surface 8 cm of soils and deeper medium and wet soils. The reduction of total porosity was mainly due to the decrease of macroporosity. Microporosity increased as a proportion of total pore space. This corresponds with the works mentioned above with the exception of Froehlich's. Obviously microporosity in our case was relatively stable.

Logs pulled by skidder across plots between the skidder ruts affected bulk density and porosity, but the effects could not be quantatively related to the treatments. For example, the path of skidded logs from one turn to the next varied widely between the ruts. Consequently, the number of turns that logs passed over a given location during a six turn treatment could have ranged from none to six turns. Results of bulk density and porosity showed the variation. A distinct pattern among turns and moisture treatments could not be established.

CONCLUSIONS AND SUMMARY

The influence of trafficking during simulated log skidding on soil bulk density and porosity in Smithdale sandy loam was tested over three soil moisture regimes. Porosity decreased and bulk density increased with increasing turns of the skidder, and these changes occurred rapidly, within 3 turns of the skidder.

Changes in porosity and bulk density were closely related to soil moisture content. Within the soil moisture range examined, bulk density increased and porosity decreased with increasing soil moisture.

Changes in bulk density and porosity were greatest at the soil surface. Very little change occurred at deeper depths in soils with 2.9 percent soil moisture. In soils with 14.2 to 16.4 percent soil moisture changes in bulk density and porosity were noted throughout the 24 cm depth studied.

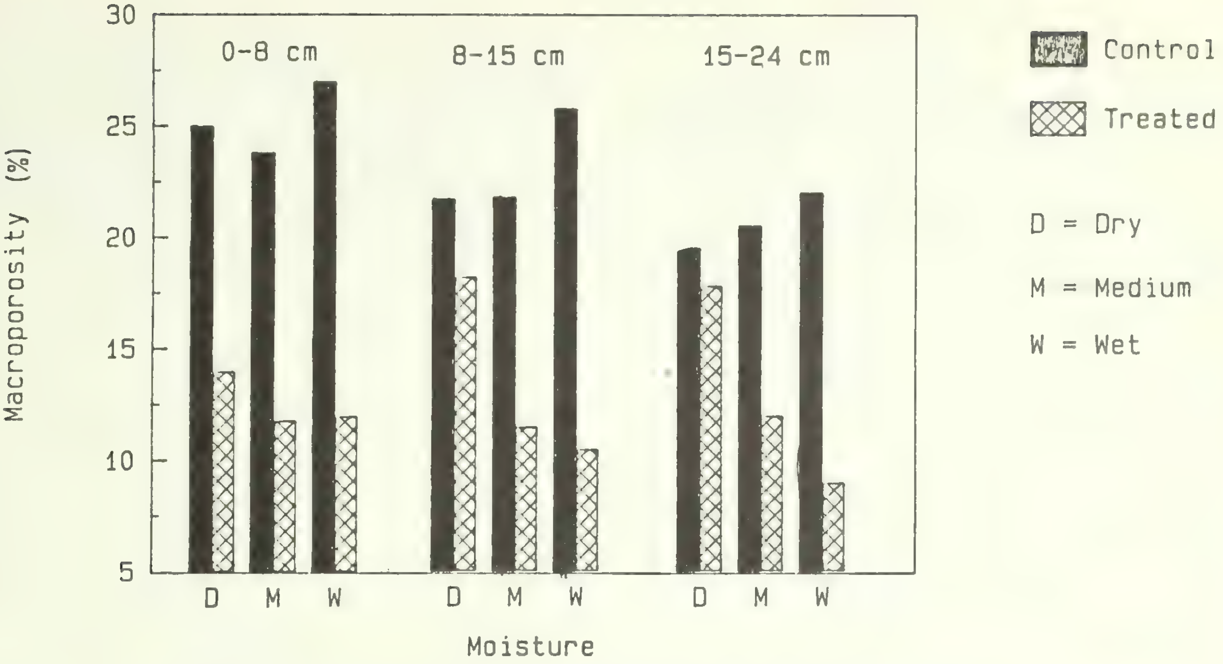

Figure 3. The changes in macroporosity associated With soil moisture and depth

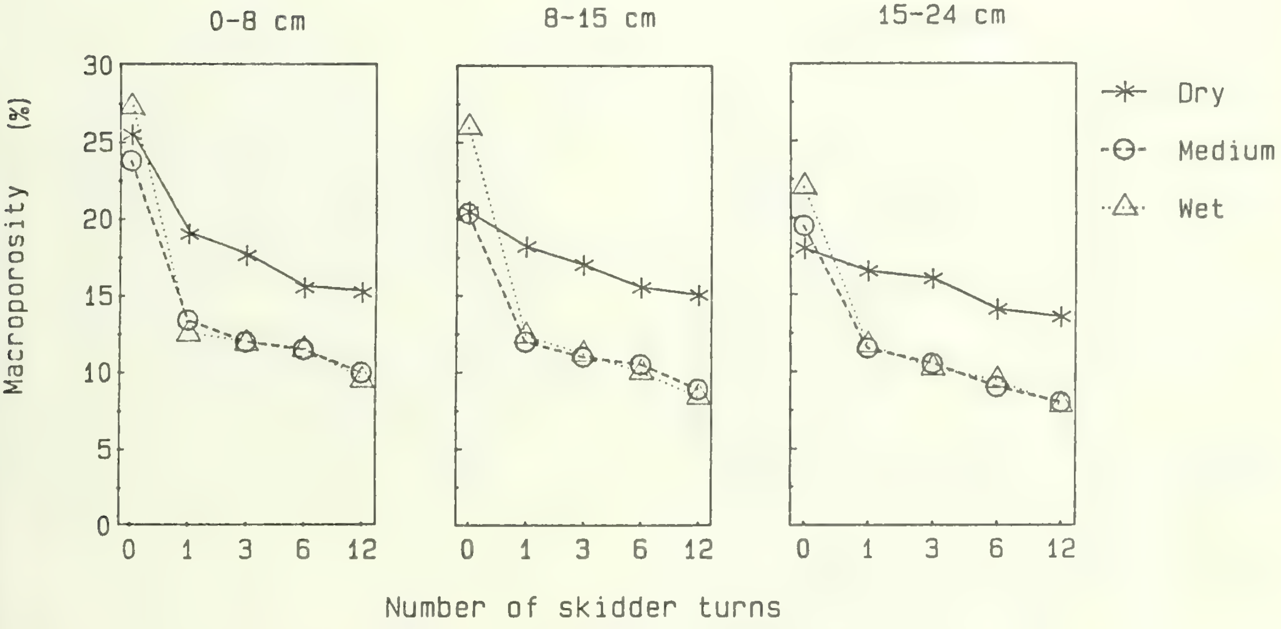

Figure 4. The changes in macroporosity associated with number of skidder turns, soil moisture and depth

In summary, bulk density increased and porosity decreased rapidly with increasing turns of the skidder as soil moisture content increased from about 3 to 16 percent in the Smithdale sandy loam studied. The depth to which these changes occurred were greatest with 16 percent soil moisture. To minimize disturbance, logging on this soil should be scheduled during summer and fall which are typically dry periods in north-central Mississippi. The number of skid trails should be minimized by retraversing a skid trail when possible.

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CHANGES IN NET PRIMARY PRODUCTIVITY AND CELLULOSE DECOMPOSITION RATES IN A WATER TUPELO - BALD CYPRESS SWAMP FOLLOWING TIMBER HARVEST[1]

Stephen F. Mader, W. Michael Aust, and Russ Lea[2]

Abstract.--First-year responses of aboveground net primary productivity and cellulose decomposition rates following clearcutting were determined for a water tupelo - bald cypress swamp in southwestern Alabama. Responses of helicopter- and skidder-logged plots were compared to each other, and an adjacent, undisturbed reference stand. Additionally, cellulose decomposition was measured on plots treated with herbicide to control the effect of revegetation on decay rates. The tupelo-cypress swamp showed rapid, early recovery of two important ecosystem functions, indication of high resilience from disturbance[3].

INTRODUCTION

The National Wetlands Policy Forum, convened at the request of the Environmental Protection Agency, has recommended that the federal government disallow "overall net loss of the nation's wetlands" and implement a long-term program to "increase the quantity and quality of wetlands" (The Conservation Foundation 1988). Within this context, it is evident that timber harvesting and other activities in forested wetlands must minimize short-term impacts and enhance recovery rates of fiber production, as well as an array of associated ecosystem functions and processes (Sather and Smith 1984). In light of increasing regulatory pressure, informed ecommendations for forestry Best Management ractices are needed.

This study was designed to assess relative recovery rates of ecosystem functions following timber harvesting disturbances. Net primary productivity (NPP) and cellulose decomposition rate, two important and useful indices of ecosystem-level environmental change, were assessed. Both show an integrated response to an array of biological and physical processes. First-year responses following timber harvesting are reported.

METHODS

Study Area

The study site was located in the Mobile River Delta of southwest Alabama, approximately 40 km north of Mobile Bay and along the west bank of the Tensaw River. The site was chosen for the homogeneity of vegetation (species, ages, heights, and stocking), soil type, hydrology, topography, and logging history. Potential regeneration from viable seed stored in soil appeared uniform. The floodplain soil is a low-bulk-density clay and is water-saturated much of the year. Diurnal tides, as well as river stage, influence water table fluctuations.

Treatments

Operable harvesting methods for the Delta are limited to wide-tired or tracked skidders during non-flood events and helicopters. Skidders represent the greatest potential for soil impact, while helicopters minimize soil impact

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[1] Paper presented at Fifth Biennial Southern ilvicultural Research Conference, Memphis, TN, ovember 1-3, 1988.

[2] Graduate Research Assistants and Director, espectively, Hardwood Research Cooperative, ollege of Forest Resources, North Carolina State niversity, Raleigh, NC 27695.

[3] The authors gratefully acknowledge Scott Paper mpany, Southern Timberlands, Saraland, AL 36571, r financial and logistical assistance in support this research.

during logging. In the first treatment area, an unloaded Franklin 105 skidder with 86-cm-wide tires travelled over and disturbed 54 percent of the soil surface. In the second treatment area, a Bell 205 helicopter removed merchantable stems, which avoided machinery impact to the site. In both treatments, stumps were cut to approximately 50 cm above the ground and unmerchantable stems at least 5 cm dbh were felled and left in place. A third treatment in early June included application of the herbicide glyphosate and the manual cutting of surviving sprouts to prevent revegetation. In this way, the effect of revegetation on soil cellulose decomposition rates was controlled. Lastly, the fourth treatment area was an undisturbed forest, which was included to compare treatment responses of NPP and cellulose decomposition to baseline levels. The undisturbed forest was a 70-year-old water tupelo and bald cypress swamp with 99.1 percent canopy closure, 514 stems at least 20 cm dbh per hectare, and basal area (trees >20 cm dbh) of 67 m2/ha. Harvesting was performed during fall 1986, and first-year responses were measured during the 1987 growing season.

Treatment Layout and Experimental Design

Three treatments -- skidder, helicopter, and herbicide -- were applied to square, 0.36-hectare plots across a 23-hectare clearcut. Three contiguous 3x3 Latin squares provided statistical control over environmental gradients, both parallel and perpendicular to the Tensaw River. There were nine replications of each treatment. Additionally, the fourth treatment -- undisturbed forest -- was located within the same original stand and adjacent to the clearcut. Undisturbed forest was divided into nine "dummy plots" to balance statistical tests.

Data Collection

Net Primary Productivity.--Vegetation was divided into four sampling components. The herbaceous component consisted of all herbaceous plants, vines, and woody plants less than 50 cm tall. The understory component included shrubs and trees at least 50 cm tall, but less than 4 cm dbh. The midstory included trees from 4 cm to 20 cm dbh. The overstory component included only trees at least 20 cm dbh. Scientific names of plants mentioned in the text are provided in Table 1. The herbaceous component was sampled destructively in 108 clip plots (0.5 m2) per treatment in both late-June and early-October and yielded estimates of peak annual aboveground production (Boring and others 1981). The understory component was sampled nondestructively on 72 plots (25 m2) per treatment (Doumlele and others 1984). Stems were tallied by species and 0.5-cm diameter classes before and after the growing season. Regression equations were developed for each species to convert stem counts to biomass using the methodology of Boring and Swank (1984). Wood production of midstory vegetation was sampled by remeasurement of tree diameters and heights on 18 0.004-hectare fixed-area circular plots (Phillips and Saucier 1982). Appropriate equations for biomass conversions were applied (Clark and others 1985, McNab and others 1983). Wood production of overstory was estimated similarly for permanently marked trees around 18 BAF 7 (metric) prism points. Foliage production of midstory and overstory combined was estimated by monthly collections of litterfall into 36 baskets (0.22 m2). All NPP estimates are reported as aboveground dry weight.

Table 1. –Scientific names of plants mentioned in text.

Common name	Scientific name
Arrow-arum	Peltandra virginica (L.) Kunth
Bald cypress	Taxodium distichum (L.) Richard
Bur-head	Echinodorus cordifolius (L.) Griesbach
Carolina ash	Fraxinus caroliniana Miller
Climbing hempweed	Mikania scandens (L.) Willd.
Eclipta	Eclipta alba (L.) Hassk.
Greenbrier	Smilax laurifolia L.
Knotweed	Polygonum punctatum Ell.
Marsh-fleabane	Pluchea camphorata (L.) DC
Purple nut sedge	Cyperus erythrorhizos Muhl.
Water primrose	Ludwigia glandulosa Walt.
Water tupelo	Nyssa aquatica L.
Water-willow	Justicia ovata (Walt.) Lind.

Organic Matter Decomposition.--A technique using tensile strength losses of soil burial cloth was chosen as an index for organic matter decomposition potential because of an established methodology (Latter and Howson 1977). The cloth is 93 percent cellulose, the main constituent of plant organic matter, and is designed to minimize substrate variability and enable precise tests of treatment effects. Greater strength losses of the fabric indicate more-rapid decay rates. Values of tensile strength loss were annualized and transformed (linearized) to yield the cotton rate of rotting (CRR), an index that permits direct comparisons between treatments (Hill and others 1985). Cloth was inserted vertically into the soil and left for nine days (July 14-23, 1987). Seven measurements were recorded across each profile at 5-cm intervals from 0 to 30 cm depth.

RESULTS

Total Aboveground Net Primary Productivity

Aboveground NPP, by treatment and vegetation component, is reported in Table 2. Total NPP of the undisturbed forest was 1170 g/m2/yr. Most of the year's production was overstory wood and foliage. Midstory, understory, and herbaceous components, collectively, played a minor role in total stand NPP. Mortality actually exceeded growth for the understory component. Water tupelo, bald cypress, and Carolina ash made the greatest contributions to the NPP of the undisturbed forest, with 83 percent of the total accounted for by water tupelo alone. NPP of the undisturbed forest was lowest in plots farthest from the Tensaw River.

Total NPP within the clearcut ranged from 522 g/m2/yr for the helicopter treatment to 762 g/m2/yr for the skidder treatment. NPP of the herbicide treatment was assumed nil. Paired contrasts, following analysis of variance among the three clearcut treatments, indicated that NPP of the helicopter treatment was significantly greater than the herbicide treatment, as expected. Surprisingly, total NPP of the skidder treatment was significantly greater than the helicopter treatment (table 3). Differences among NPP means along environmental gradients both parallel and perpendicular to the river were not significant, although NPP decreased with increasing distance from the Tensaw River. For the helicopter and skidder treatments, total NPP was 45 and 65 percent of the undisturbed forest. All of the plant species catalogued in the undisturbed forest were also detected in the skidder and helicopter areas in the first growing season after clearcutting.

Table 2.--Aboveground net primary productivity (NPP) by vegetation component and species during the first year following clearcutting and timber harvest.

Component	NPP Undisturbed forest	 Helicopter	 Skidder
		--g/m2/yr--	
Overstory/midstory			
Water tupelo	974	0	0
Bald cypress	141	0	0
Carolina ash	51	0	0
Other	2	0	0
Subtotal	1168[1]	0	0
Understory			
Carolina ash	-6	109	73
Water tupelo	0	62	57
Bald cypress	0	7	3
Other	0	3	2
Subtotal	-6	181	135
Herbaceous			
Purple nut sedge	0	217	507
Knotweed	0	32	57
Water primrose	0	9	17
Eclipta	0	15	3
Greenbrier	3	9	4
Water-willow	1	9	4
Climbing hempweed	0	9	3
Arrow-arum	0	6	5
Marsh-fleabane	0	2	4
Bur-head	0	5	1
Other	4	28	22
Subtotal	8	341	627
All components			
Total	1170	522	762

[1] Overstory stems and branches = 722 g/m2/yr, midstory stems and branches = 27 g/m2/yr, and combined litterfall = 419 g/m2/yr.

Table 3.--Partial analysis of variance results for aboveground net primary productivity by vegetation component.

Contrast	Df	F	Significance[1]
Understory component			
Helicopter vs. herbicide	1	188	***
Helicopter vs. skidder	1	12	***
Herbaceous component			
Helicopter vs. herbicide	1	102	***
Helicopter vs. skidder	1	71	***
All components			
Helicopter vs. herbicide	1	159	***
Helicopter vs. skidder	1	34	***

[1] *** = significant at the .01 confidence level.

Within the herbaceous component, the NPP response of the skidder treatment (627 g/m2/yr) was nearly double that of the helicopter treatment (341 g/m2/yr). However, understory NPP was greater for the helicopter treatment (181 g/m2/yr) than for the skidder treatment (135 g/m2/yr). Paired contrasts within vegetation components showed highly significant differences among treatment means (table 3).

Sixty species were detected in the herbaceous component. The most productive species were purple nut sedge, knotweed, water primrose, eclipta, greenbrier, water-willow, climbing hempweed, arrow-arum, marsh-fleabane, and bur-head (table 2). Purple nut sedge alone accounted for 64 and 81 percent of the NPP for helicopter and skidder treatments, respectively. Purple nut sedge, water primrose, water-willow, arrow-arum, and bur-head peaked in late June, while the others peaked in early October, indication that sampling twice within the growing season was worthwhile.

Nine plant species were detected in the understory component of skidder and helicopter plots, but only two exhibited important productivity values: Carolina ash produced 73-109 g/m2/yr and water tupelo produced 57-62 g/m2/yr (table 2). The difference in NPP values between the skidder and helicopter treatments is attributed to machinery impact. Reduction in understory NPP due to skidding was 33 percent for Carolina ash, but only 8 percent for water tupelo.

Densities of first-year tree regeneration following helicopter and skidder treatments were

Table 4.--Stem density of regeneration for the first year after clearcutting by species group and height class.

Species group	Helicopter <50 cm tall[1]	Helicopter ≥50 cm tall[2]	Skidder <50 cm tall[1]	Skidder ≥50 cm tall[2]
	--Number per hectare (thousands)--			
Desirable[3]	50.6 (±103.5)	8.4 (± 7.3)	49.3 (±106.4)	6.5 (±6.3)
Total	54.4 (± 97.1)	21.6 (±11.5)	60.7 (±118.6)	17.6 (±8.8)

[1] n = 108 plots per treatment.
[2] n = 72 plots per treatment.
[3] Water tupelo and bald cypress.

calculated for two height classes. Of the total stems (less than 50 cm tall) per hectare, 91 percent of the helicopter stems and 83 percent of the skidder stems were the desirable water tupelo or bald cypress, and most were of seedling origin (table 4). Sixty-six and 70 percent of 0.5-m2 plots were stocked with at least one tupelo or cypress seedling or sprout following skidder and helicopter treatments, respectively. Of the total stems (at least 50 cm tall) per hectare, 39 percent of the helicopter and 37 percent of the skidder stems were desirable, and most originated as stump sprouts.

Organic Matter Decomposition Rates

Tensile strength losses of soil burial cloth revealed an important pattern of cellulose decomposition rates among treatments. Cotton rate of rotting (CRR) was 57.0 and 57.1 for the helicopter and skidder treatments, respectively (fig. 1). Analysis of variance failed to show differences in cellulose decay rates between the helicopter and skidder treatments (table 5). Both had significantly slower rates than the herbicide treatment (64.1), where plant cover was removed. CRR was slowest in undisturbed forest soil (43.4), where dense shade and cooler soil temperatures were maintained. Further partitioning of variance showed a highly significant pattern of decreasing cellulose decay rate with increasing depth in the soil profile.

Table 5.--Partial analysis of variance results for cellulose decomposition rate (CRR).

Contrast	Df	F	Significance[1]
Helicopter vs. herbicide	1	6	*
Helicopter vs. skidder	1	1	NS

[1] * = significant at the .10 confidence level. NS = not significant.

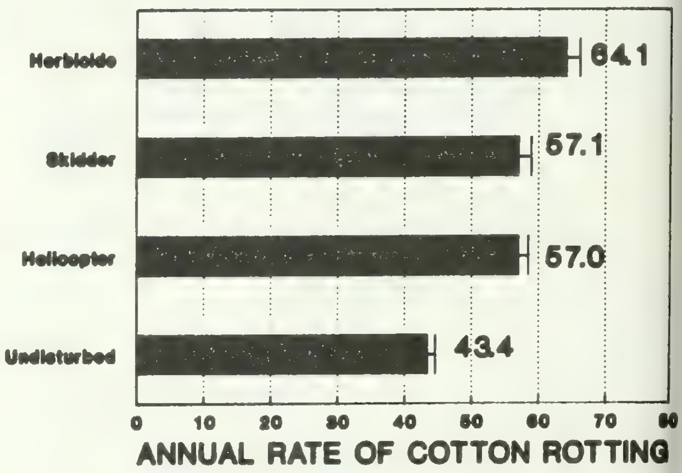

Figure 1.--Soil cellulose decomposition rates (CRR) and standard errors for mid-July 1987.

DISCUSSION AND CONCLUSIONS

Productivity of undisturbed Delta forests (1170 g/m2/yr) is higher than most upland hardwood stands; for example, an undisturbed southern Appalachian hardwood stand produced only 887 g/m2/yr (Boring and others 1981). Delta forest productivity is intermediate in magnitude relative to other forested wetlands, which range from 712 to 1780 g/m2/yr (Brinson and others 1981). First-year responses of NPP for both helicopter and skidder treatments were high -- 45 and 65 percent of undisturbed forest NPP, respectively. Values of total NPP were 2.5 to 10 times greater than the first-year responses of southern Appalachian hardwoods and other early-regenerating temperate forests (Art and Marks 1971; Boring and others 1981). Recovery of NPP following helicopter logging was only two-thirds the value for the skidder treatment; helicopter logging did not show an advantage over skidder logging with regard to early recovery of total NPP. The large percentage of first-year productivity exhibited by the herbaceous component should be viewed as a positive aspect toward site recovery; this important ecosystem function has been maintained, albeit at reduced levels, until a new tree crop is firmly reestablished. However, the greater response of understory NPP after helicopter treatment may indicate a slight advantage regarding future NPP of the site. Neither treatment showed an advantage in production of water tupelo, the preferred commercial tree species. Regeneration of desirable species appears adequate to ensure a fully stocked future stand, even after worst-case mortality estimates are applied. Most stems will be water tupelo stump sprouts, with water tupelo and bald cypress seedlings filling canopy openings.

CRR of the undisturbed forest soil is four times faster than that reported for a cool temperate forest in July (Hill and others 1985). Removal of vegetation by the herbicide treatment resulted in a 50-percent increase over CRR of the undisturbed forest. Although significance tests failed to show differences in soil cellulose decomposition rates between helicopter and skidder treatments, both were intermediate between the undisturbed forest and herbicide treatment extremes. This indicates that soil cellulose decomposition rates slow and approach preharvest levels as vegetative regrowth occurs. The return of a slower organic matter decomposition rate is important in restoring nutrient cycling to equilibrium levels and lessening the potential for nutrient losses from the site.

The responses of plant productivity and rate of organic matter decomposition in the Delta indicate rapid recovery of important ecosystem functions following clearcutting and high ecosystem resilience following disturbance. If trends continue, with nutrient fluxes equilibrating and structural diversity of vegetation becoming more complex, long-term disruption of important ecosystem functions should be minimal. Continuation of this study is planned through the second and succeeding growing seasons.

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ABIOTIC CHANGES OF A TUPELO-CYPRESS SWAMP FOLLOWING HELICOPTER AND RUBBER-TIRED SKIDDER TIMBER HARVEST[1/]

W. Michael Aust, Stephen F. Mader, and Russ Lea [2/]

ABSTRACT. _ _ _ A tidal palustrine water tupelo (Nyssa aquatica L.)-baldcypress (Taxodium distichum (L.) Rich.) swamp in southwestern Alabama was subjected to helicopter and rubber-tired skidder harvesting methods during fall, 1986. An adjacent undisturbed stand served as a control. Relative treatment impacts were determined by an investigation of soil physical, soil chemical, and hydrological properties. Measured soil physical properties were mechanical resistance, saturated hydraulic conductivity, and temperature. Examinations of soil chemical properties included reduction-oxidation potential, acidity, oxygen percentage, and total nitrogen and phosphorus of the soil water. Hydrology was quantified as seasonal and daily water table fluctuations and sedimentation rates. These parameters were used as indices of ecosystem functional changes. Values are reported for two growing seasons following harvest.[3/]

INTRODUCTION

Wetland ecosystem functions provide many important benefits and values to society (Brinson and others 1984; Greeson and others 1984; Mitsch and Gosselink 1986; Odum 1984). Sather and Smith (1984) acknowledged five major categories of wetland functions: hydrology, water quality, nutrient cycling, habitat, and socio-economic. Although the importance of forested wetlands is widely recognized, effects of disturbance upon wetland ecosystem functions have not been adequately established (Adamus and Stockwell 1983).

Currently, several federal, state, and private natural resource organizations are developing best management practices (BMPs) for timber harvesting in wetland forests (Solomon 1988), despite limited quantitative research. The objectives of this research are to quantitatively describe the relative impacts of two operational timber harvesting methods upon the hydrology, soil physics, and soil chemistry of a specific forested wetland, and to use these properties as indices of ecosystem functional changes.

METHODS

Study Site

The Mobile-Tensaw River Delta is a fluvial deltaic plain located in southwestern Alabama, below the confluence of the Tombigbee and Alabama Rivers. Eastern and western boundaries are formed by the Southern Pine Hills escarpment; Mobile Bay is the southern border (O'Neil and Mettee 1982). Three major channels dissect the Delta: the Mobile, Middle, and Tensaw Rivers. Numerous streams and channels meander between major drains. At the southern fringe of the Delta salt marshes exist, further north tupelo-cypress-ash swamps are prevalent.

The actual study site is located on the western bank of the Tensaw River, approximately in the center of the Delta. This site has a logging history typical of the region; pull-boat logging occurred between 1910 and 1920, selective float-logging was used during the mid-1800's. Harvests prior to the mid-1800's were sporadic. In 1986, the existing stand and site reflected past cutting practices. Numerous pull-boat channels were visible and a two-aged stand was evident. Most of trees were 70-years-old, but scattered trees were 130-years-old. Over 80 percent of the stand's trees were water tupelo; other common tree species were baldcypress and Carolina ash. Average total basal area exceeded 75 m^2/ha (325 ft^2/acre), while total volume exceeded 95 cords/acre.

[1/] Paper presented at Fifth Biennial Southern Silvicultural Conference, Memphis, TN, November 1-3, 1988.

[2/] Graduate Research Assistants and Director, respectively, Hardwood Research Cooperative, College of Forestry, North Carolina State University, Raleigh, NC.

[3/] Financial and logistical support provided by Scott Paper Company, Southern Timberlands, Saraland, AL.

The soil is a homogeneous, vertic fluvaquent shrink-swell clay, containing less than 5-percent organic matter. Mean bulk density equaled 0.54 g/cm^3. Soils are commonly saturated for 8 to 10 months per year, with overbank floods occurring during winter and spring. Topography, exclusive of the higher, narrow natural levee, was flat, varying less than 15 cm.

Treatments

Four treatments were selected for the study: (1) undisturbed, (2) helicopter, (3) skidder, and (4) helicopter / herbicide. The undisturbed area served as a control, providing a basis for relative comparisons of treatment effects. Helicopter and rubber-tired skidder harvest methods were chosen due to their operational prevalence in the Delta region. Glyphosate herbicide application was used in order to compare soil physical and chemical properties and hydrology of vegetated versus nonvegetated areas. The helicopter, skidder, and herbicide treatments are collectively referred to as disturbed treatments.

The undisturbed, or control, treatment plots could not be incorporated within the disturbance treatment area because of problems associated with shading, transpiration, and harvesting. Therefore, an undisturbed area was established adjacent to disturbance treatments, within the same original site/stand (fig. 1). Preharvest measurements confirmed similar vegetation, hydrology, soil, topography, and past use.

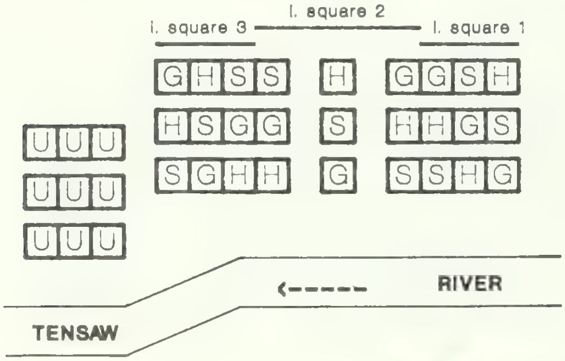

Figure 1. Experimental design and plot layout. Treatments are helicopter (H), skidder (S), herbicide (G), and undisturbed (U).

Implementation of helicopter, skidder, and herbicide treatments followed standard felling procedures. These consisted of chainsaw felling of unmerchantable stems larger than 5 cm at dbh and directional felling of all merchantable stems. Thus, a biological clearcut was achieved by fall, 1986.

For the helicopter treatment, a Bell 205^{TM} helicopter having 2000 Kg lift capacity was used. Limbed and topped merchantable stems were choked and flown to a nearby log deck.

The skidder treatment utilized a Franklin 105^{TM} skidder that had 86-cm-wide tires. Approximately 54 percent of all skidder treatment plots were uniformly trafficked, realistically simulating normal skidder operations in the Delta.

Glyphosate (Rodeo^{TM}) herbicide was selected for the herbicide treatment due to its broad control spectrum, soil inactivity, and federal labeling for wetland application. Backpack sprayers were used to apply 1.75 percent solutions annually, following helicopter harvesting. Good vegetation control was achieved.

Data Collection

Daily and seasonal fluctuations of the water table were monitored with a Stevens type F^{TM} stage recorder and "dipstick" wells. Four pvc wells were located in each plot on a 40*40 m spacing. Data from the stage recorder and wells were used to continuously estimate the water table depth of each plot.

Saturated hydraulic conductivities were obtained in both 1987 and 1988 growing seasons for all treatments using the auger hole method (Amoozegar and Warrick 1986). Four stations were located in each plot on the 40*40 m grid. At each station, saturated hydraulic conductivity was obtained for 10-cm segments of the soil profile, from the soil surface down to 50-cm depth.

Soil reduction-oxidation (redox) potential, soil acidity (pH), and soil temperature were measured twice (spring and summer) each growing season after harvest. Four stations existed in each plot, spaced 40*40 m. Five measurements of these parameters were collected at each station, between 0- and 50-cm soil depth, in 10-cm intervals. Redox potential, soil acidity, and soil temperatures were measured with a portable Markson model 95^{TM} mV-pH-temperature meter. Platinum electrodes were used for redox measurements (Bartlett 1986; Bohn 1971), KCL/Ag/AgCl type probes were used for pH measurements (Peech 1965) and a YSI thermistor probe was used for soil temperature measurements (Taylor and Jackson 1986).

Soil oxygen percentages were obtained at the same stations and depths as redox potentials. A Markson portable oxygen analyzer and galvanic probe were used.

Nine sedimentation bars were placed in each plot on a 15*15 m grid. A washer was welded to each bar and inserted flush with the soil surface. After flood events the depth of sedimentation was measured.

Soil mechanical resistance was measured with a Soil Test^{TM} cone penetrometer (American Society of Agricultural Engineers 1986; Bradford 1986). Nine stations were located in each plot on the 15*15 m grid. At each station, mechanical resistance values were obtained in 10-cm intervals, beginning at the soil surface and ending at 50-cm depth.

Soil water samples were taken from the four pvc wells in each plot. Samples were acidified with H_2SO_4 and stored at 4° C until analysis (Environmental Protection Agency 1979). Total Kjeldahl N was determined by flow injection analysis (Latchet 1987); total dissolved P was determined by inductively coupled plasma (ICP) spectrometry (Allied Analytical Systems 1984).

Statistical Design and Plot Layout

A Latin square statistical design (Steele and Torrie 1980) was selected because it enables differentiation of treatment effects and two-dimensional gradient effects. Ecological gradients are common within wetland ecosystems (Brinson and others 1985). Each treatment was replicated 9 times. The complete treatment layout included three 3*3 Latin squares for the three disturbance treatments, while 9 "dummy" replications were established in the undisturbed control area (fig. 1). Each treatment plot measures 60*60 m (0.36 ha). Total size of the clearcut area, including treatments, buffers, and access lanes equals 22.8 ha, thus approximating the size of an operational harvest. Undisturbed control plots contain an additional 7.6 ha.

RESULTS AND DISCUSSION

Hydrology is the dominant controlling force of forested wetlands (Day and others 1988; Wharton and others 1982) and it influenced all parameters investigated in this study. Seasonal patterns of water table fluctuations (fig. 2) reflect that 1987 and 1988 were dissimilar years.

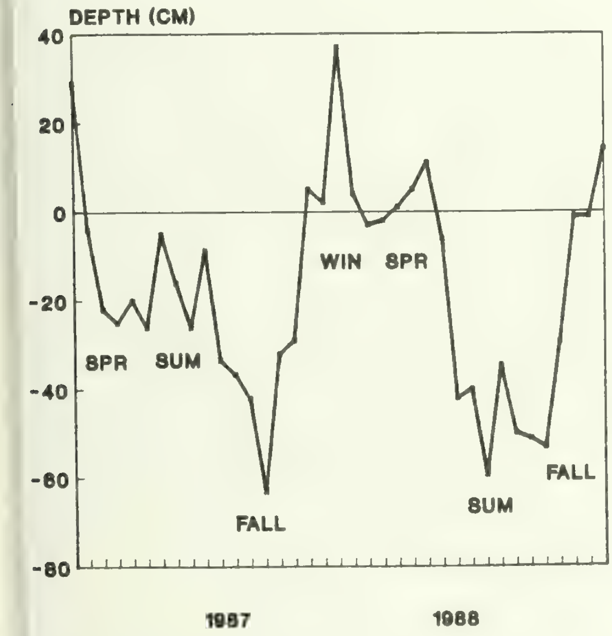

Figure 2. Seasonal water table fluctuations.

During spring, 1987, the water table was above the soil surface. As evaporational rates increased in the late spring, water levels dropped below the soil surface. Frequent thunderstorms, rapid rates of soil water movement, and river tidal fluctuations acted, in concert, to maintain the water table level approximately 15 cm below the soil surface for most of the summer. During the relatively rain-free fall, the water table was reduced to a 1987 minimum. Overbank flood events occurred in the winter and spring of 1987-1988, resulting in higher water tables. The preceding pattern is typical of the region. Late spring and summer, 1988 were droughty, therefore the water table of the second growing season was 30- to 40-cm lower than the previous growing season. Hurricanes in the late summer and fall, 1988 caused heavy rainfalls and an unusually high fall water table. Overall, 1987 was a typically wet growing season, while 1988 was an unusually dry growing season, although moisture was not limited in the usual sense.

During the wetter months of the years, there were no treatment differences concerning water table depth. During the growing season, the undisturbed control plots had a significantly lower water table (alpha=0.05), nearly 17 cm lower than the disturbed treatments. Higher transpirational rates and deeper root systems of the mature forest probably account for this pattern. No statistically different water table depths were found between the three disturbed treatments.

Daily patterns of water table fluctuations did not reveal treatment differences, but they did reveal the soil's relatively high recharge capacity. During a 'typical' summer day, the water table would be lowered by 8 mm, then it would recharge 5 mm at night.

Mechanical resistance, saturated hydraulic conductivity, redox potential, soil acidity, soil oxygen percent, and soil temperature were all measured at five depths. However, simpler understanding of the relative treatment effects can be obtained by averaging values of all soil depths. Further discussion of these variables will focus on these averages.

Hydrology had a large influence upon soil mechanical resistance values, which estimate shear resistance or strength of a soil (Bradford 1986; Greacen and Sands 1980). During the skidder-logging simulation, the water table was above the soil surface. Saturated soil conditions existed and average bulk density equalled 0.54 g/cm^3, indicating an extremely soft mineral soil. Skidder tires sank into this soft soil, but did not compact it. Instead, the soft, saturated soil responded similar to a fluid and flowed to either side of the rut (Greacen and Sands 1980). Analysis revealed that skidder and helicopter treatments were significantly more compacted than the control (alpha=0.05), yet the skidder treatment was not significantly different from the helicopter treatment in 1987 (table 1). During the 1988 growing season, no differences were found for mechanical resistance between any treatment. This is probably due to the natural recovery rate of the shrink - swell clays and indicates rapid recovery of mechanical resistance, which influences ecosystem nutrient cycling.

Table 1. Average mechanical resistance (kPa) of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	kPa	
Helicopter	1439	1375
Skidder	1446	1783
Herbicide	1335	973
Undisturbed	1262	1140

Saturated hydraulic conductivity partly regulates soil water flux to plant roots and drainage of excess water from the soil profile (Hillel 1982; Mitsch and Gosselink 1986). Therefore saturated hydraulic conductivity is an index of hydrology, water quality, and nutrient cycling functions. Although soils were not more compacted by the skidder than helicopter, saturated hydraulic conductivity was significantly lower for skidder plots than helicopter plots (alpha=0.05). Also, all disturbed treatments had significantly lower saturated hydraulic conductivity values than undisturbed control plots (table 2).

Table 2. Average saturated hydraulic conductivity (cm/hr) of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	cm/hr	
Helicopter	8.0	9.0
Skidder	2.9	3.8
Herbicide	8.2	6.7
Undisturbed	17.1	18.4

Apparently soil disturbance resulting from falling trees reduced all disturbance treatment values, but the skidder treatment had the most severe reduction of saturated hydraulic conductivity. Although skidder activities did not compact the soil more than the other disturbance treatments, the passage of the tires through the soil reduced the soil macroporosity and blocked channels of flow, thus, altering soil drainage. A similar pattern existed for both years. Because saturated hydraulic conductivity influences water movement within the soil, soil redox potential, acidity, oxygen percent, and total N of the soil water were also changed, particularly following skidder treatment.

Reduction of the soil is the most important chemical change brought about by submergence (Ponnamperuma 1972). Redox potential is correlated to element availability and toxicity (Bohn 1971), nitrogen fixation and loss, and organic matter decomposition (Bartlett 1986; Grable 1966; Reddy and Patrick 1975). Callebaut and others (1982) found that redox potentials generally decrease as flood duration increases. Much wetter conditions existed in 1987 than in 1988; therefore, all 1987 redox potentials were significantly lower (alpha=0.05). Both years exhibit the same treatment patterns and relative differences. Undisturbed plots had significantly higher redox values than the disturbance treatments (alpha=0.05). Within the disturbance treatments, helicopter and herbicide treatments were statistically equal, and skidder plots had significantly lower redox potentials (table 3). These redox patterns reflect the treatment values for saturated hydraulic conductivity; fastest rates for the undisturbed, slowest rates for the skidder, and intermediate rates for helicopter and herbicide treatments. The implication is that hydrology, water quality, and nutrient cycling functions related to soil reduction have been most radically altered by the skidder treatment.

Table 3. Average redox potential (mV) of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	mV	
Helicopter	106	271
Skidder	80	182
Herbicide	98	286
Undisturbed	115	405

If soil oxygen is limited, plant root respiration may also be limited (Kramer and Kozlowski 1979; Mitsch and Gosselink 1986). When a soil is submerged or saturated, exchange of oxygen is severely impaired, particularly if the water is stagnant (Conner and Day 1976; Harms 1973; Shanklin and Kozlowski 1985). During 1987, saturated soil conditions prevailed and there were no treatment differences, basically soil oxygen was 0.1 percent for all treatments. Drier conditions existed in 1988 and treatment differences could be detected (table 4). Oxygen percent was significantly higher for the undisturbed areas than for the disturbed plots (alpha=0.05). Within the disturbance treatments, no significant differences were detected, although average oxygen percentages were lowest on the skidder treatments, possibly creating poorer conditions for plant growth. Possible explanations of the higher oxygen values of the undisturbed treatment include better drainage (higher saturated hydraulic conductivity) and a lower water table during the growing season.

Soil acidity (pH) has little direct effect upon plant growth, but it can strongly influence availability of plant nutrients and toxins (Grable 1966). Ponnamperuma (1972) stated that the basic effect of soil inundation is to increase the pH of acid soils and decrease the pH of alkaline soils towards neutrality. The two growing seasons had different hydrologic regimes, which were reflected by the higher soil pH of 1987 versus the lower soil pH of 1988. Although actual pH values were significantly different between the two years (alpha=0.05), similar treatment patterns existed (table 5). The undisturbed area, with its better drainage and lower water table, had the most acid soil; poorly drained skidder plots had less acid soil. Helicopter and herbicide treatments had intermediate rates of water movement and soil acidities.

Table 4. Average soil dissolved oxygen percent of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	O_2 %	
Helicopter	0.1	2.1
Skidder	0.1	1.4
Herbicide	0.1	1.8
Undisturbed	0.1	5.4

Table 5. Average soil acidity (pH) of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	pH	
Helicopter	5.1	4.4
Skidder	5.4	4.6
Herbicide	5.1	4.4
Undisturbed	4.9	4.0

Soil temperature has been shown to influence plant jrowth, and processes of physical, chemical, and nicrobiological nature (Taylor and Jackson 1986). Soil emperature values for the growing seasons of 1987 and 988 reveal vegetation's strong influence upon nicroclimate. Undisturbed and shaded treatment plots were ignificantly cooler for both growing seasons; fully exposed ierbicide plots were significantly warmer for both years alpha=0.05). During 1987, the helicopter and skidder lots grew dense herbaceous vegetation and some woody lants. Temperatures were statistically equal for these two reatments, both were significantly different from the ooler undisturbed and warmer herbicide treatments (table). The same pattern held for 1988 with one exception; elicopter treatment was significantly cooler than the kidder treatment. Cover was 50 percent higher for the elicopter areas, due primarily to better crown expansion f tupelo and ash sprout growth that occurred there.

Table 6. Average soil temperature (°C) of five soil depths for two growing seasons by treatment.

Treatments	1987	1988
	°C	
Helicopter	25.4	24.2
Skidder	25.4	24.8
Herbicide	26.5	26.2
Undisturbed	23.3	23.7

Nitrogen and phosphorus are the two most commonly recognized pollutants in water quality studies (Canter 1985; Sather and Smith 1984). Primary mechanisms of nitrogen removal from water are nitrification and denitrification (Brinson and others 1984; Patrick and Tusneem 1972; Ponnamperuma 1972). Ammonium is nitrified, or converted to nitrate, by aerobic bacteria in aerated soils. As the soil becomes anaerobic, denitrification of nitrate to elemental dinitrogen gas occurs and the nitrogen is removed from the system (Brinson and others 1984; Patrick and Tusneem 1972). Total nitrogen values of the soil water for the undisturbed, helicopter, and herbicide plots were not significantly different from each other (alpha=0.05), but all contained significantly more nitrogen than did the skidder areas (table 7). Skidder areas had poorer drainage and lower redox potentials, which are better conditions for nitrogen loss via denitrification.

Table 7. Average total Kjeldahl N and dissolved P of the soil water for 1987 by treatment.

Treatment	Total N	Total P
	ppm	
Helicopter	10.6	11.4
Skidder	7.4	10.2
Herbicide	11.1	9.8
Undisturbed	11.0	8.8

Removal of phosphorus by wetlands is due to absorption by organic matter, formation of iron and aluminum precipitates (Mitsch and others 1979; Sather and Smith 1984), or sediment trapping (Adamus and Stockwell 1983). There were no significant treatment differences of total P of the soil water between any treatments (table 7).

Removal of sediments by wetlands is viewed as being beneficial to water quality (Adamus and Stockwell 1983; Bedinger 1983; Boto and Patrick 1979). The helicopter and skidder treatments were not significantly different from one another (table 8), but they did trap significantly more sediments than either undisturbed or herbicide treatments (alpha=0.05). Dense cover of herbaceous and woody plants increased the surface roughness of the skidder and helicopter plots and reduced flood velocities more than on undisturbed and herbicide plots, thus, trapping more sediments.

Table 8. Average sediment accumulation (mm) for the 1987-1988 flood season by treatment.

Treatments	Sediment
	mm
Helicopter	2.2
Skidder	1.2
Herbicide	0.7
Undisturbed	1.1

CONCLUSIONS

Hydrology is the driving force of this forested wetland and hydrology regulates ecosystem functions. Disturbance treatments altered hydrology in two distinct ways. First, clearcutting reduced the transpirational rate and resulted in the undisturbed treatment having a lower water table during the growing season. Encouragingly, helicopter and skidder treatments are revegetating at a rapid rate and transpirational differences are expected to return to preharvest levels. Second, disturbance treatments had lower rates of saturated hydraulic conductivity, particularly for the skidder treatment. Skidder ruts altered soil drainage, resulting in lower soil redox potentials, soil acidity, oxygen and total N of the soil water. Therefore, the skidder resulted in more and greater soil physical and chemical changes than did the helicopter method of logging, implying greater functional alterations, perhaps of longer duration.

Water quality was also influenced in two ways. Helicopter and skidder treatments had an abundance of stumps, slash, woody sprouts and seedlings, and herbaceous plants. These two treatments trapped more sediments, indicating improved water quality. Additionally, skidder plots had lower amounts of total N in the soil water. This was probably due to the lowered rates of saturated hydraulic conductivity and redox potentials, which can improve water quality by increasing denitrification.

Nutrient cycling changes were indicated in the previous discussion of altered hydrology, saturated hydraulic conductivity, soil acidity, redox potential, oxygen, sedimentation, and total N of the soil water. Total P of the soil water did not show alterations. Mechanical resistance had treatment differences during the first year, but not for the second year, indicating recovery. Soil temperature differences were obviously related to plant shading effects. Temperatures of helicopter and skidder plots are expected to return to undisturbed temperatures, perhaps most rapidly on helicopter plots due to better soil conditions for plant growth.

The overall implication of this research is that most indices of functional change were altered by disturbance treatments. Not all changed in the same direction or degree. In general, the helicopter treatment was less affected during the first two growing seasons following harvest than the skidder treatment. However, skidder areas apparently improve water quality more than the undisturbed area. Recommendations for forestry BMPs should consider all potential impacts in order to optimize forested wetland values.

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Pest Management

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GLOBAL CLIMATE CHANGE: IMPLICATIONS FOR SILVICULTURE AND PEST MANAGEMENT[1]

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Abstract.--Due to human activities, the level of CO_2 and other trace gases in the atmosphere has increased. These changes in atmospheric composition will result in increases in global temperature. The best estimates for the southern U. S. (30°N to 35°N latitude) are an annual increase of about 1.5 to 3.0°C by the year 2050. This predicted change has important implications for forest insect pest management and silviculture. Implications of direct and indirect effects of changing climate on forest insects are discussed. A specific example illustrating the effect of climate change on losses from southern pine beetle attack is presented.

INTRODUCTION

Burning of fossil fuels, deforestation and other technological changes have resulted in a increase in the levels of carbon dioxide (CO_2) and other trace gases in the Earth's atmosphere which have caused and will continue to cause changes in the global climate.

Due to human activities, the level of CO_2 and other trace gases in the atmosphere have increased appreciably since the 19th century. Increases in CO_2 of 25% are estimated since 1850 and they have resulted in temperature increases of about 0.3 to 1.1°C (MacCracken and Kukla 1985). Without further increases in CO_2, the Earth is committed to additional warming of at least 0.1-1.0°C (MacCracken and Kukla 1985). Furthermore, a doubling of atmospheric CO_2 concentration is expected by late in the next century. This additional increase will result in an estimated additional average global warming of 1-4°C (Schlesinger and Mitchell 1985). However, the magnitude of the temperature change will vary over the Earth's surface with the smallest changes near the equator and the largest increases in the upper latitudes (Schlesinger and Mitchell 1985). The best estimates of temperature change for 30°N to 35°N latitude (southeastern United States) are an increase of about 1.5-3.0°C (Schlesinger and Mitchell 1985).

Global climate change will also affect patterns of precipitation and soil moisture. Most general circulation models predict increases in mean precipitation and evaporation rates of 3-7% for a doubling of CO_2 (Schlesinger and Mitchell 1985). These studies show a marked increase in precipitation at high latitudes and smaller changes, if any, at the equator. However, an increase in temperature also increases the capacity of the atmosphere to hold moisture and as a result there could be a marked reduction in soil moisture at some latitudes (Schlesinger and Mitchell 1985). In response to a doubling of the CO_2 concentration, Manabe and Wetherald (1986) estimate a reduction in June to August soil moisture of 20-30% for 30°N to 35°N latitude. However, there is some controversy surrounding these results (MacCraken et al. 1986), and they must therefore be considered tentative.

In summary, most general circulation climate models predict an increase in global average temperature of 3.5 to 4.2°C due to a doubling of CO_2. For the southern United States an increase in the average annual temperature of 1.5-3.0°C is predicted. There may also be a corresponding reduction in summer soil moisture of 20-30%, although this estimate is less precise than the projected increases in temperature.

The objective of this paper is to describe the possible direct and indirect effects of global climate change on forest insect pests. An example of potential effects on losses from the southern pine beetle is outlined (see Hedden 1987 for other examples). Furthermore, the policy implications of global climate change on integrated forest pest management are discussed.

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DIRECT EFFECTS ON FOREST INSECT PESTS

The direct effect of climate change on forest insect pests will be those of changing temperature and moisture on insect growth and survival. Insects are cold blooded organisms (poikilotherms) and their development is temperature dependent. For each species there exist well defined tolerance limits above and below which growth ceases and mortality occurs. Also, between these limits there is an optimum temperature at which development and survival is maximized. The optimum temperature for different life stages and activities may differ. However, tolerance limits and optimum temperatures have been established through adaptation to the historically prevailing climatic conditions existing in the insect's habitat. Increasing temperatures could result in more favorable conditions during some times of the year, especially winter, and less than optimal conditions during the summer. Each species will vary from all others in its reaction to changing conditions.

Moreover, some insect species possess an adaptation called diapause which allows the organism to survive periods of adverse environmental conditions. Diapause is a period when physiological activity in the insect is greatly reduced. Another purpose of diapause is the synchronization of the life cycle. This survival strategy is especially important for insects with a single generation per year, allowing them all to enter a single stage of development at the same time. Diapause can occur during any stage of insect development, and for many insects in the southern United States diapause occurs during the winter. The beginning of diapause is usually initiated by reduced day length. Termination of diapause is normally in response to temperature, usually some combination of cold exposure (chilling) and increasing temperature (accumulation of heat units). If diapause is induced by changes in day length, then it is unlikely that increasing temperatures will affect the initiation of diapause. However, warmer temperatures might cause diapause to terminate early and accelerate development of the insect. These changes might result in an increase in the number of insect generations per year.

Other species of insects have no diapause. These insects are active and grow whenever environmental conditions are suitable. They may respond to extremes in temperature or moisture by entering a period of quiescence. The difference between this strategy and diapause is that quiescence ceases immediately when environmental conditions return to normal.

Whether an insect species does or does not diapause, higher temperatures could result in an increase in the number of generations per year. In the case of some rapidly reproducing insects the addition of just one more generation per year could dramatically increase population numbers, and result in significant additional pest impact (Ford 1982).

Direct effects of increased atmospheric CO_2 concentration should be minor. Insects evolved 10^8-10^7 years ago during a period of elevated CO_2 concentration (300-3000 ppm) and temperature. Therefore, they may be preadapted to the changes in CO_2 concentration projected for the next century. One direct effect that has been noted is that the spiracular valves of some insects open more often in CO_2 rich environments. This change could have some adverse affect on the internal moisture balance of the insect (Lincoln et al. 1984).

Regardless of how a species responds to environmental conditions, forest insects possess a high reproductive potential, especially in comparison to the long-lived trees upon which they depend for survival. Conceivably, insects can rapidly adapt to changes in climate and at a rate at least an order of magnitude faster than trees. This difference means that insects should have an advantage in the coevolutionary battle between herbivores and trees, at least in the short term.

INDIRECT EFFECTS ON FOREST INSECT PESTS

The indirect effects on forest insect pests will be due to the influence of changing climate on individual tree species and forest stands. Increasing temperature, elevated CO_2 concentration, and changes in precipitation have the potential to dramatically alter tree growth and species composition in the southern United States. The only studies on the effect of CO_2 on tree growth have dealt with short-term effects on seedlings. To date, possible effects on older trees and forest stands can be arrived at only through speculation and extrapolation of results from studies with young plants.

A combination of temperature, solar radiation and relative humidity determines the atmospheric energy available for photosynthesis and transpiration. Precipitation and soil characteristics control the available soil moisture. Soil moisture and atmospheric energy together determine actual evapotranspiration and foliar water stress. In addition to water stress, photosynthesis is controlled by light and nutrient availability.

Tree seedlings show an increase in biomass when grown under an elevated CO_2 level (Rogers et al. 1983; Tolley and Strain 1985; Siniot et al. 1985; Williams et al. 1986; Retzlaff 1987). Even though atmospheric CO_2 concentration is increasing, it may still be suboptimal for photosynthesis (Retzlaff 1987). That CO_2 is a limiting nutrient is not surprising since present levels are only one-third to one-half of those 40-100 million years ago when the present species of trees evolved (Waring and Schlesinger 1985).

Accelerated early growth can reduce the time period of exposure to certain insect pests of young trees, however, increased biomass may result in an increase in the susceptible tissue available for pest infestation (Terry et al. 1984). Moreover, assuming no decreases in precipitation, increased growth in response to elevated CO_2 levels and higher temperature could result in earlier crown closure and accelerated between-tree competition. This might result in stands becoming susceptible to pests, such as bark beetles, at an earlier age.

Like insects, the seasonal growth and development of trees is primarily controlled by temperature. Each species has a seasonally dependent optimal temperature for net carbon uptake (Waring and Schlesinger 1985). Photosynthesis is adversely affected when temperatures are above or below this optimum. However, increased CO_2 concentrations could result in a shift of the temperature optimum upward (Waring and Schlesinger 1985). Assuming no other limiting factor, an uniform increase in annual temperature could also result in an extended growing season and a net increase in tree growth. For instance, Hopkin's Bioclimatic Law states that seasonal phenomena in the eastern United States such as the initiation of growth for a plant species or emergence of an overwintering insect species will occur four days sooner for every 1° latitude southward (Ford 1982). In the southern United States, a shift of 1° latitude is equivalent to about a 1°C change in annual temperature. Thus, a 1.5°C increase in annual temperature should accelerate seasonal activity by about one week while a 3°C change would result in a two week gain. Similar extensions in the end at the growing season are also likely. The net effect is that actively growing trees would be exposed to pests for a longer period of time.

This change in growing season may also result in a shift in the current range of forest trees (Miller 1982). Due to an altered climate some trees will be in environments less suitable for growth and survival. They will become more susceptible to pest impact in these marginal, or "offsite" areas.

Each species of tree apparently responds differently to increased CO_2 concentration, and this response is mediated by irradiance level (light) and available soil moisture (Tolley and Strain, 1985; Williams et al. 1986). Angiosperms (hardwoods) show a decrease in stomatal conductance with increasing CO_2 concentration (Tolley and Strain, 1985; Williams et al. 1986). This difference in conductance means that these species will have greater water-use efficiency, i. e., stomatal closure reduces moisture loss during transpiration. Loblolly pine, and possibly other conifers, do not exhibit a decrease in stomatal conductance with increasing CO_2 concentration (Tolley and Strain, 1985; Retzlaff 1987). Water-use efficiency in these species is probably adversely affected when the projected increase in CO_2 concentration is coupled with increases in temperature. If these trends for seedlings are extrapolated to larger trees, then pines may exhibit greater water stress relative to hardwoods during periods of drought. Increased potential for water stress in pines combined with the possibility of decreased summer soil moisture should result in trees much more susceptible to many insect pests, especially on drought prone sites in the Piedmont.

Exposure of hardwoods to increased CO_2 concentrations also results in plant tissues with reduced nitrogen concentrations (Williams et al. 1986). This increase in the C:N ratio is greatest in the leaves and least in the stem (Williams et al. 1986). Similar results have not been found with loblolly pine (Retzlaff 1987). In this species there was no change in C:N ratio with increases in CO_2 level. Since the critical nutrient for many forest insects is nitrogen, a reduction of the C:N ratio in hardwood foliage could result in the increased feeding activity of defoliators. In order to successfully complete development, these insects will have to consume a larger volume of foliage (Lincoln et al. 1984, 1986; Williams et al. 1986). However, the increase in carbon in both pines and hardwoods could result in the presence of higher levels of carbon based secondary chemicals which act as toxins or feeding deterrents for insects.

POTENTIAL IMPACT ON A SPECIFIC FOREST INSECT PEST

The southern pine beetle (SPB), Dendroctonus frontalis Zimm., is a pest of southern pines. In the southern United States, the range of the SPB is from Texas to the Atlantic Ocean, and from the Gulf of Mexico in the south to Arkansas and West Virginia in the north. This distribution roughly corresponds to the range of shortleaf pine. The first outbreaks of this pest were noted in the late 1700's, however, it is not until the early 1900's that reliable records of outbreaks are available, and it is only since 1950 that detailed data exist on the timing and severity of outbreaks (Price and Doggett 1982). Apparently, outbreaks of this pest have become more frequent and severe in the South since 1960 possibly due to a large increase in the number of susceptible pine stands (Hedden 1978; Karpinski et al. 1984).

On the Coastal Plain, the most susceptible forests consist of older, high density, pure loblolly or shortleaf pine stands located on sites where physiological stress is likely to occur, i. e., ridges (moisture deficit) and bottoms (flooding). In the Piedmont, susceptible forests most often consist of slow growing shortleaf pine stands infected with littleleaf disease. In either area, the presence of a disturbance such as a lightning or wind damage in a stand greatly increases the probability that a SPB infestation will occur. After initial attack, the rate of spot spread is apparently related to the density of the pines in the stand, a continuous source of beetles within the spot, and the overall beetle population in the region (Hedden and Billings 1979; Johnson and Coster 1978). Spot spread is greatest during outbreak years in high density pure pine stands with a large number of SPB brood trees. It is likely that the number of susceptible and high density pine stands determines the severity of a regional outbreak. However, the initiation and collapse of outbreaks are probably controlled by the combined effect of climate and weather on both the tree and the insect.

The most important effect of climate on the host tree is the degree to which stress is induced. An increase in moisture stress caused by higher temperatures could possibly increase the number of susceptible host trees. A decrease in precipitation, resulting in reduced soil moisture would have even greater adverse effect, especially if the increased moisture stress occurred during the summer months as suggested by Manabe and Wetherald (1986). However on certain sites which are now considered high risk for infestation due to excess moisture, the probability of attack could be reduced. In either case, increased growth due to an extended growing season and elevated CO_2 concentrations would result in accelerated crown closure with intraspecific competition occurring earlier in the life of the stand, and greater susceptibility to SPB attack.

Of equal or more importance as the effect of climate on the supply of susceptible host trees, is the effect of climate on SPB growth and development. Suitable climatic conditions for beetle development and survival must occur for an outbreak to be initiated and to persist. Climate, especially temperature, affects many of the life processes of the SPB. Hines et al. (1980) suggest that the following rates are temperature dependent: attack success, parent adult reemergence, egg production, egg development, larva-pupa development, and brood adult development. To this list we can add the following processes: beetle flight, mortality during dispersal, pheromone dynamics, within-tree mortality, and the interaction with symbiotic fungi and competing organisms. For each process, there exists an optimum temperature; a temperature below which the process is suboptimal and above which it is supraoptimal. If temperatures are either high enough or low enough, the activity not only ceases, but death of the beetle occurs.

Gagne et al. (1980) and Wagner et al. (1980) provide an excellent review of the effects of temperature on beetle development, emergence of brood adults, egg production and development. The reemergence rate was greatest at 30°C while beetle development and emergence was optimum at 25°C. The rates for both these processes declined above and below these temperatures. However, within a tree the SPB constructs significantly more gallery and lays a greater number of eggs at 15°C than at any other temperature. The threshold temperature for flight is 14°C, and arrival of beetles at baited traps increases exponentially with daily maximum temperature (Moser and Dell 1979), but the longevity of adult beetles outside the host tree declines exponentially with increasing temperature (Wagner et al. 1984). Optimal temperature for the growth of the symbiotic blue stain fungus is about 27°C (Fares et al. 1980a). This fungus, which is transported by the SPB, is important to the beetle for controlling the moisture content of attacked trees, and it contributes to the death of the tree through interruption of water transport in the xylem. Pheromone communication and response to attractive trees are also influenced by temperature (Fares et al. 1980b). Mild temperatures appear to be the most conducive to pheromone communication while higher temperatures ($>30^{\circ}$C) are less suitable. This may partially explain why new infestations are usually initiated in the spring and the fall. Beetles tend to remain in spots during the warm summer months as long as there is an attractive pheromone source and a supply of suitable host trees. Thus, for the most important life processes of the SPB, optimum temperatures are between 15°-30°C.

Thus, summer generations take as few as 26 days while the development time during the winter can be as long as 140 days (Thatcher and Pickard 1967). However, extremely high summer temperatures can adversely affect beetle development. Billings and Kibbe (1978) noted in east Texas, that the SPB generation in July of 1977 was 7 weeks while generation time in July 1976 was only 4.5 weeks. In July 1977 there were 16 days that temperatures were greater than 35°C, however, in July 1976 there were no days above 35°C.

In summary, above normal temperatures during the winter favor the development of SPB populations and allow the production of more beetle generations. Conversely, very cold winter temperatures will adversely affect SPB populations (Hain and Ayla 1985). Moreover, below normal summer temperatures should favor the development of large beetle infestations while higher temperatures result in slower beetle development and poorer survival.

Specifically, warmer winters in the southern portion of the beetle's range might result in more favorable conditions for dispersal and spot initiation while warmer summer temperatures could have a negative impact on summer spot growth. However, warmer temperatures in the northern portion of the range might have a positive effect on both spot initiation and spot growth.

Two analyses were performed to investigate these hypotheses. First, the probability of the SPB population in east Texas showing an increase over the previous year was modeled as a function of temperature. Second, SPB spot growth in east Texas and north central Georgia was simulated using a temperature driven infestation growth model (Stephen and Lih 1985).

The probability that the number of individual SPB infestations would increase from the previous year was modeled using logistic regression. The probability of change was modeled rather than the actual or percentage change in the number of infestations because the actual number of beetle spots in a year represents not only the response of the beetle to climate, but also the number of susceptible pine stands available for infestation.

Data on the annual number of SPB spots in east Texas for the period of 1958-1983 were used to determine population changes. If the number of infestations increased from one year to another it was assigned a value of 1, if the population declined or remained the same it was assigned a 0. This dependent variable was used as input into a logistic regression program (Harrel 1986). The independent variables were the sum of the monthly deviations, in °C, from long-term average temperature for the period of October of the previous year through February of the current year (OCT), and the sum of the deviations for the period of June through August of the current year (JUN). The temperature data was obtained for monthly weather summaries of east Texas. For the period of 1958-1962, the values for Lufkin, TX were used. After 1962, the values for the east Texas climate district were used. Other variables tested include the number of SPB spots in the previous year, the trend of the population for the previous year over the year before it (0-decline, 1-increase). These variables were included to test for the presence of significant autocorrelation in the data.

The analysis resulted in the following model: $P = Z / (1+Z)$, where P is the probability of an increase in the number of SPB infestations for the year, and $Z = EXP(2.588+0.599*OCT-0.742*JUN)$. The standard errors for the regression coefficients were 1.57 for the intercept, 0.287 for OCT, and 0.391 for JUN. A year is predicted to have an increase in the number of infestations over the previous year if the value of P is greater than or equal to 0.5. A value of less than 0.5 indicates a declining population. The model was statistically highly significant (P=.0002). The model was validated using a procedure where each year was omitted, one at a time, and the regression equation was refit. The equation was then used to predict the probability of population change for the missing year. Overall 80% (20/25) of the years were correctly classified while increasing and decreasing years were correctly classified 87% (13/15) and 70% (7/10), respectively.

The model was then used to estimate the effect of increasing temperatures on predicted SPB population change. The average annual temperature for each year from 1958-1983 was systematically increased by 0°C (no change) to 5°C, and the number of years with predicted population increase and decrease was recorded. The results (table 1) indicate that SPB populations in east Texas will increase with increasing temperature.

Table 1.--Effect of increasing temperature on the probability of the southern pine beetle population increasing over the previous year

Population Change:	Temperature Increase (°C): 0	1	3	5
Increase	15	18	22	23
Decrease	10	7	3	2
% Increase	60	72	88	92

These increases are the result of above normal winter temperatures. Mild winter temperatures allow the SPB to remain active during periods when conditions for beetle development and dispersal might otherwise be suboptimal. An additional beetle generation during this period of the year could have tremendous impact on the initiation of new spots. Warmer winter temperatures would be even more important at the northern limits of the range of the SPB where seasonal activity is initiated as late as April or May (Hain and Ayla 1985).

While high summer temperatures do have a negative impact on SPB development and survival, the impact on the total number of infestations would probably be small. A more likely result might be infestations of smaller average size.

The effect of changing climate on SPB spot growth was evaluated using the infestation growth model developed at the University of Arkansas (Stephen and Lih 1985). Spot growth is modeled in two phases: 1) the within-tree process of SPB brood development, and 2) the between-tree attack process. Both of these phases are temperature dependent. Long-term monthly average temperature profiles can be modified to simulate the effect of changing climate.

Specifically, the May to October average monthly temperatures for the period of 1931-1960 for the north central Georgia climate division (includes Atlanta, Gainesville and Athens) and the east Texas climate division (includes Longview, Nacogdoches and Lufkin) were used as input for the model. Growth of SPB spots was simulated using the long-term average (ambient) temperature, and monthly average temperature increased by 1.5°C and by 3.5°C. Stand conditions were held constant for each simulation: 1) pure loblolly pine, 2) 45 years-old, 3) 12 in. dbh, and 4) basal area of 150 sq. ft./ac. The initial SPB population was also held constant at 100 active brood trees per spot. All simulations were run for a 30 day period. The variable of interest was the number new trees infested during this 30 day period.

Simulation results for east Texas indicate that spot growth will decline during the summer (June-September) as temperature increases, but will be higher in May, October and November when cooler temperatures prevail (table 2). The depression of spot growth with increasing temperature agrees with the observations of

Billings and Kibbe (1978) which showed that unusually high temperature in July 1977 resulted in a beetle generation 2.5 weeks longer than in July of 1976 when more mild temperatures prevailed. The results of the simulation also indicate that average temperatures in May, October and November may be less than optimal for spot growth. Increases in spot growth during October and November might result in a larger pool of beetles available for dispersal and initiation of new spots in late winter and early spring. Thus, the results of the spot growth simulations support the results obtained from the model of SPB population change which indicate that beetle populations in east Texas will increase as average annual temperature increases.

Table 2.--Average number of trees killed in 30 days in a southern pine beetle infestation in a 45 year-old loblolly pine stand in east Texas

Month	Temperature increase: 0°C	1.5°C	3.5°C
May	198	206	209
June	160	146	125
July	132	117	103
August	138	122	105
September	189	187	167
October	190	211	232
November	118	146	188
Average	161	162	161

The simulation results for north central Georgia indicate that lower than optimal temperature is probably limiting SPB spot growth in every month except July and August (table 3). Increasing temperature will have a significant overall positive influence on spot growth, especially during October and November (table 3). This positive impact on spot growth will probably be even more dramatic at more northern latitudes in North Carolina and Virginia, especially in the Piedmont and Mountain regions of these states.

In summary, an increase in global temperature and CO_2 will probably result in increased pine mortality due to attack by the SPB and other related bark beetles. Conditions for beetle development and survival will improve in many areas, while at the same time, the number of susceptible pine stands will increase or at least remain at the present level. This high level of beetle activity will continue until the supply of susceptible pine stands is depleted (Hedden 1978), a situation which is occurring today in some areas of the southern United States, most notably in southeast Texas (Billings et al. 1985).

Table 3.--Average number of trees killed in 30 days in a southern pine beetle infestation in a 45 year-old loblolly pine stand in north central Georgia

Month	Temperature increase: 0°C	1.5°C	3.5°C
May	171	189	205
June	164	165	150
July	149	146	124
August	157	154	135
September	167	181	189
October	134	155	187
November	68	92	124
Average	144	155	159

IMPLICATIONS FOR THE FUTURE

Potential global climate change has important implications for the management of southern forests, including the integrated management of forest pests. The general overview, and specific examples provided in this paper on the possible effects of climate change on forest insect pests leads to the following observations:

1. The specific effects of climate change on forest insects are difficult to predict. Therefore, it will be difficult to predict which pests will cause increased impact on forests, and which will cause less impact. However, some forest insects which presently are not considered pests may cause significant damage in the future. Furthermore, due to the time-scale of climate change, it will be difficult to associate changes in pest activity with slowly changing phenomena such as increased temperature, decreased soil moisture, higher CO_2 levels, etc.

2. One effect of climate change will be a shift in the current range of forest trees (Miller 1982). Due to a changing climate some trees will be in environments less suitable for growth and survival. They will become more susceptible to pest impact in these marginal, or "offsite" areas.

3. Because of the short generation time of insects relative to that of trees, insects will be able to adapt to changes in climate faster than trees. This difference in reproductive rate will probably result in an increase in pest impact lasting until the most vulnerable forest stands or tree species are eliminated.

4. Forest industry forests will be impacted less than public or private nonindustrial forests. Forest industry stands generally have shorter timber rotations, and most large companies have aggressive tree breeding programs. This combination of factors means that forest industry will be able to breed trees

quickly, and to establish forests that preform well in a climatically altered environment. Consequently, pest losses related to climate change will likely be concentrated in public and private nonindustrial forests.

5. The nature of the interaction between changing climate and atmospheric deposition is unclear. The combined effect of changing climate and atmospheric deposition on losses from forest pests can not be predicted. However, significant atmospheric deposition would result in reduced tree vigor. In general, increases in tree stress result in greater susceptibility to forest pests.

6. Forest management can ameliorate the impact of forest pests. The appropriate use of silvicultural techniques to promote tree vigor will help prevent losses from most forest pests. Use of techniques such as planting pest resistant species or varieties of trees, controlling competition (weed control, thinning, etc.), sanitation cutting, and minimizing adverse disturbance to the site during harvest and site preparation will result in healthier forest stands. Reducing timber rotations to avoid having low vigor, overmature stands will also result in reduced pest losses.

The overall lack of precision with which predictions can be made about the effect of changing climate on forest pests is understandable. It is extremely difficult to even predict forest pest losses from year to year. However, past experience has proven that appropriate forest management is the single most important factor in reducing pest losses. Therefore, if forestry is practiced in a scientific manner for the long-term good of society, then losses from forest pests under changing climatic conditions will be minimized.

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SITE/STAND FACTORS INFLUENCING NANTUCKET PINE TIP MOTH IN LOBLOLLY PINE PLANTATIONS[1]

David L. Kulhavy[2], William G. Ross, James R. Meeker and William David Tracey

Abstract. -- Tip moth infestation and loblolly pine growth were examined on sandy, loamy and clayey sites in 2-3 year old plantations. Infestations were greatest on loamy sites. Following fertilizer and herbicide applications, tip moth infestations were lowest on fertilized plots following application of phosphorus.

INTRODUCTION

Pine tip moths, particularly the Nantucket pine tip moth, *Rhyacionia frustrana*, are important insect pests of young pines in the southeastern United States, central California and part of New Mexico. Damage caused by tip moths causes loss in height growth, stem deformation, loss in wood quality, bushy appearance, and in severe instances, tree mortality (Yates et al. 1981). Forestry trends, in an effort to maximize fiber and timber production, have resulted in the establishment of increasing acres of pine plantations. These plantations are susceptible to tip moths during early growth (ages 1-5) and populations of tip moths and numbers of damaged tips vary according to site/stand factors and tree species. In the southeastern United States, loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*) are the favored hosts.

Generally, the more suitable the host trees are to the site, the less severe the damage (Wakeley 1928, Yates 1960). Intensive vegetation management often results in increased tip moth infestation rates. Phosphorus fertilizers tended to reduce tip moth infestations while increased nitrogen did not (Pritchett and Smith 1972).

In Texas, site preparation intensity, site index, tree age, tree height, depth of the soil A horizon times the soil texture (from sand to clay) and soil texture at 61 centimeters, were significant factors in classifying plantations as either low or high hazard to tip moths (White et al. 1984). In South Carolina, Hood (1986) found site intensity preparation, site index, depth to A horizon and soil calcium significant variables for predicting tip moth infestations.

This paper reports on tip moth infestation and host tree growth related to cultural treatments and contrasting soil types (sand, silt, clay) in East Texas.

METHODS AND MATERIALS

Typic Quartzipsamments (fine sand)

Study plots were established in January 1983 on Typic Quartzipsamments (Tonkawa series), 10 km. west of Garrison, Nacogdoches County, Texas. Seven treatments were established of four replicates of 48 seedlings each, at 2.5 m x 2.5 m spacing, with a similar buffer between replicates. The treatments include:

1. bare-rooted loblolly pine (LP);
2. Terra-Sorb treated LP;
3. clay-slurry treated LP;
4. bare-rooted slash pine (SP);
5. Terra-Sorb treated SP;
6. clay-slurry SP; and
7. containerized longleaf.

Details of plot layout, four year survival and soil texture are presented in Kroll et al. (1985) and Kulhavy et al. (1987).

Aquic Paleudult (fine sandy loam)

On an Aquic Paleudult, (Kullit series), tip moth infestation rates were investigated following treatments of fertilizers and herbicides on a two-year old loblolly pine plantation. Four treatments in a randomized block design with four replicates on 0.2 hectare plots were applied as follows:

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[1] Paper presented at Southern Silvicultural Research Conference, Memphis, Tennessee, November 1-3, 1988.

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1. control (no treatment);
2. fertilizer (ammonium nitrate, 34-0-0, applied at a rate of 660 Kg/ha; 225 Kg/ha N; and concentrated superphosphate (0-46-0) at a rate of 280 Kg/ha; 56 Kg/ha P);
3. herbicide (hexazinone, 420 gm/ha; and sulfumeturon methyl, 210 gm/ha);
4. fertilizer + herbicide (treatments 2+3).

Fertilizers were applied by hand with measured amounts evenly distributed within a 0.5 m radius around each tree. Herbicides were applied by a boom sprayer following label instructions. Tip moth infestation rates, height, diameter and volume (ht. x dia^2) were measured at the end of the 1987 growing season and analyzed using one-way analysis of variance and Duncan's multiple range test.

Tip Moth Infestation Rates on Contrasting Soil Types.

Tip moth infestation rates were measured on fine sand (Typic Quartzipsamments), loamy fine sand (Plinthic Paleudults) and a very fine sandy loam over a clay (Vertic Hapludalfs) over two seasons (1985-1986). Infestation rates were related to tree and soil nutrition, soil and tree moisture and tree growth characteristics. Infestation rates were measured on 25 trees over three plots on three to four year old loblolly pine plantations in Nacogdoches and Angelina Counties. Details of sampling procedures are outlined in Meeker (1987).

RESULTS AND DISCUSSION

Typic Quartzipsamments

Six year survival is reported in Table 1. The decline in survival from 1984-1986 was due to drought during the summer seasons. Tip moths and town ants (Atta texana) were not currently present on the site. Height and diameter measurements of loblolly pine indicated significantly taller trees for clay slurry compared to Terra-Sorb treated and untreated trees; and significantly larger diameter for clay slurry compared to Terra-Sorb treated trees. Volumes were also significantly larger for clay slurry trees (Table 2). Computing a survival volume index (percent survival x height x $diameter^2$) indicated no difference between clay-slurry (0.74) and Terra-sorb (0.70), but both had a greater volume index than control (0.26).

Conclusions are that Terra-sorb treated trees had greater survival, but currently, clay slurry and Terra-sorb treated trees both occupy the same growing volume. Additional monitoring is required to examine the long-term height and diameter growth.

Table 1.--Percent survival of loblolly, slash and longleaf pine, on Typic Quartzipsamments, six year results.

Treatment	October				
	1983	1984	1985	1986	1988
Longleaf Pine	85.2	56.5	56.0	56.0	54.0
Loblolly (Terra-Sorb^R)	81.3	50.8	46.5	40.1	38.0
Loblolly (Clay Slurry)	49.2	31.9	31.3	29.2	28.0
Loblolly (Untreated)	50.5	19.6	21.3	21.3	14.0
Slash (Terra-Sorb^R)	46.9	20.8	16.2	14.6	14.0
Slash (Clay Slurry)	35.4	16.9	12.0	10.4	10.0
Slash (Untreated)	41.4	16.9	23.5	14.1	10.0

Table 2.--Height, diameter and survival volume index of loblolly pine, on Typic Quartzipsamments, six year results.

Treatment	Height (mean ± SD)	Diameter (mean ± SD)	Survival Volume Index
	m	cm	
Control	3.09±0.85a[1]	7.8±2.2ab	0.26
Terra-Sorb	3.56±0.98b	7.2±2.4a	0.70
Clay Slurry	3.93±1.04c	8.2±2.3b	0.74

[1] Means followed by same letter not significantly different at P = 0.05 using Duncan's multiple range test.

Table 3.--Mean percent NPTM infestation rates, Aquic Paleudult (Kullit series), Nacogdoches County, Texas, 1987.

Treatment	Number of Trees Measured	Mean Infestation
		percent
Control	76	10.21b[1] ± 9.0 S.D.
Fertilizer (56 Kg/ha P + 225 Kg/ha N)	77	6.28a ± 7.3 S.D.
Herbicide (420 gm/ha hexazinone and 210 gm/ha sulfumeturon methyl)	76	10.12b ± 9.4 S.D.
Fert. + Herb.	77	9.73b ± 9.7 S.D.

[1] Means followed by same letter not significantly different at P = 0.05 using Duncan's Multiple Range Test.

Table 4.--Mean height and diameter measurements in centimeters (cm) following fertilizer and herbicide applications, loblolly pine plantation, Aquic Paleudult (Kullit series), Nacogdoches County, Texas, 1987.

Treatment	Pre-Season Height March, 1987	Post-season Height October, 1987	Mean Growth	March Dia.	Oct. Dia.	Mean Growth
	cm	cm	cm	cm	cm	cm
Control	50.7	111.6a[1]	60.89a	1.47	2.13a	0.64a
Fertilizer (56 Kg/ha P + 225 Kg/ha N)	55.5	124.7b	69.2b	1.65	2.31ab	0.66ab
Herbicide (420 gm/ha hexazinone and 210 gm/ha sulfumeturon methyl)	50.5	109.0a	59.0a	1.55	2.36ab	0.81b
Fert. + Herb.	55.6	128.0b	72.4b	1.55	2.59b	1.04c

[1] Means followed by same letter not significantly different at P = 0.05 using Duncan's Multiple Range Test.

Fertilizer/Herbicide Treatments

NPTM infestation rates were calculated on a whole tree basis as the ratio of apparently infested tips to total tips. Infestation rates at the end of the 1987 growing season were homogeneous with the exception of those receiving fertilizer, which were significantly lower (Table 3). Reasons for this effect are unclear, but host vigor enhancement may increase overall resistance by increasing resin production, which is the trees' major physiological defense against NPTM larvae. The increased competing vegetation following fertilization may also have provided improved habitat for NPTM predators and parasites, and, in some cases, hindered access to trees by ovipositing females. This may partially explain the apparent negation of the fertilizer effect by the addition of herbicide (Table 3).

Height growth was significantly greater on plots receiving fertilizer and fertilizer plus herbicide, while diameter growth was best on fertilizer plus herbicide and herbicide treatments (Table 4). The fertilizer treatments, while stimulating height growth, also stimulated competing vegetation. This had little effect on height growth, but restricted diameter growth. Herbicide treatments, in suppressing competing vegetation, allowed for greater diameter growth.

Tip Moth Infestation Rates on Contrasting Soil Types

Individual tree measurements and site/stand factors indicated lower tip moth populations with increased levels of phosphorus in both the foliage and upper 15 cm of the soil on all three sites. The higher the silt content in the soil, the larger the tip moth populations. In 1986, measurement of tree moisture content indicated higher infestation rates with lower moisture stress. The three soil types examined produced three contrasting systems of host type and corresponding levels of tip moth infestation. The sandy soil had the lowest nutrient levels and soil moisture leading to thin branches and low tip moth populations. The clayey site had the highest nutrition levels and soil moisture content and moderate infestations in 1985 and low in 1986. The loamy site, with the highest percentage of silt, had moderate nutrient levels and soil moisture. Periodic rains resulted in hosts of moderate heights and diameters. Tip moth infestation rates were the highest on this site for both 1985 and 1986.

Poor growth of host trees corresponded to low infestation rates. Moderate growth of host trees corresponded to the highest infestation rates. Vigorous growth corresponded to moderate to low infestation rates, (a highly desirable host is produced, but success of attacks is limited).

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Hood, W.M. 1986. Hazard rating forest sites for pine tip moth (Rhyacionia spp.) in northwestern South Carolina. Athens, Georgia: University of Georgia. 54 p. Ph.D. dissertation.

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Slash (Clay Slurry)	35.4	16.9	12.0	10.4	10.0
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Treatment	Number of Trees Measured	Mean Infestation
		percent
Control	76	10.21b[1] ± 9.0 S.D.
Fertilizer (56 Kg/ha P + 225 Kg/ha N)	77	6.28a ± 7.3 S.D.
Herbicide (420 gm/ha hexazinone and 210 gm/ha sulfumeturon methyl)	76	10.12b ± 9.4 S.D.
Fert. + Herb.	77	9.73b ± 9.7 S.D.

[1] Means followed by same letter not significantly different at P = 0.05 using Duncan's Multiple Range Test.

Table 4.--Mean height and diameter measurements in centimeters (cm) following fertilizer and herbicide applications, loblolly pine plantation, Aquic Paleudult (Kullit series), Nacogdoches County, Texas, 1987.

Treatment	Pre-Season Height March, 1987	Post-season Height October, 1987	Mean Growth	March Dia.	Oct. Dia.	Mean Growth
	cm	cm	cm	cm	cm	cm
Control	50.7	111.6a[1]	60.89a	1.47	2.13a	0.64a
Fertilizer (56 Kg/ha P + 225 Kg/ha N)	55.5	124.7b	69.2b	1.65	2.31ab	0.66ab
Herbicide (420 gm/ha hexazinone and 210 gm/ha sulfumeturon methyl)	50.5	109.0a	59.0a	1.55	2.36ab	0.81b
Fert. + Herb.	55.6	128.0b	72.4b	1.55	2.59b	1.04c

[1] Means followed by same letter not significantly different at P = 0.05 using Duncan's Multiple Range Test.

Fertilizer/Herbicide Treatments

NPTM infestation rates were calculated on a whole tree basis as the ratio of apparently infested tips to total tips. Infestation rates at the end of the 1987 growing season were homogeneous with the exception of those receiving fertilizer, which were significantly lower (Table 3). Reasons for this effect are unclear, but host vigor enhancement may increase overall resistance by increasing resin production, which is the trees' major physiological defense against NPTM larvae. The increased competing vegetation following fertilization may also have provided improved habitat for NPTM predators and parasites, and, in some cases, hindered access to trees by ovipositing females. This may partially explain the apparent negation of the fertilizer effect by the addition of herbicide (Table 3).

Height growth was significantly greater on plots receiving fertilizer and fertilizer plus herbicide, while diameter growth was best on fertilizer plus herbicide and herbicide treatments (Table 4). The fertilizer treatments, while stimulating height growth, also stimulated competing vegetation. This had little effect on height growth, but restricted diameter growth. Herbicide treatments, in suppressing competing vegetation, allowed for greater diameter growth.

Tip Moth Infestation Rates on Contrasting Soil Types

Individual tree measurements and site/stand factors indicated lower tip moth populations with increased levels of phosphorus in both the foliage and upper 15 cm of the soil on all three sites. The higher the silt content in the soil, the larger the tip moth populations. In 1986, measurement of tree moisture content indicated higher infestation rates with lower moisture stress. The three soil types examined produced three contrasting systems of host type and corresponding levels of tip moth infestation. The sandy soil had the lowest nutrient levels and soil moisture leading to thin branches and low tip moth populations. The clayey site had the highest nutrition levels and soil moisture content and moderate infestations in 1985 and low in 1986. The loamy site, with the highest percentage of silt, had moderate nutrient levels and soil moisture. Periodic rains resulted in hosts of moderate heights and diameters. Tip moth infestation rates were the highest on this site for both 1985 and 1986.

Poor growth of host trees corresponded to low infestation rates. Moderate growth of host trees corresponded to the highest infestation rates. Vigorous growth corresponded to moderate to low infestation rates, (a highly desirable host is produced, but success of attacks is limited).

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SOUTHERN PINE BEETLE-MICROORGANISMS-HOST INTERACTIONS: INFLUENCE OF COMPOUNDS PRODUCED BY CERATOCYSTIS MINOR[1]

J. D. Hodges, T. E. Nebeker, C. A. Blanche,
R. Honea, T. H. Fisher, and T. P. Schultz[2]

Abstract.--Phenolic (isocoumarin type) compounds produced by microorganisms associated with the southern pine beetle (SPB) could be important in overcoming tree resistance to the beetle and in death of the tree. One compound, 6,8 dihydroxy-3-hydroxy methyl isocoumarin, greatly stimulates water loss in cut twigs or seedlings of loblolly pine, apparently by decreasing stomatal control of water loss. Field tests with large trees indicate loss of stomatal control after attack by the SPB and thus suggest possible involvement of isocoumarin compounds.

INTRODUCTION

The overall objective of this work on the southern pine beetle (SPB) is a better understanding of relationships between the beetle, its associated microorganisms, and host tree. Specifically, it is designed to study possible mechanisms whereby the beetle is able to overcome the natural resistance of trees and eventually kill them.

Successful attack by the SPB invariably results in death of the tree. Girdling of the stem during gallery construction seemed at first to be the obvious reason for tree death, but it now seems clear that girdling alone cannot account for the rapid decline of the tree. Several species of fungi are known to be associated with the SPB (Francke-Grossman 1965, Barras 1967, Barras and Perry 1972, Bridges and Perry 1987). Early investigations implicated the blue-stain fungus *Ceratocystis minor* (Hedgc.) Hunt in death of trees (Caird 1935, Craighead and St. George 1938, Bramble and Holst 1940). It was assumed that invasion of vascular tissues by the fungus prevented upward movement of water either by blockage or by introduction of air which would break the water column within tracheids (Mathre 1964), thus resulting in severe moisture stress and tree death. Anderson (1960) suggested several mechanisms by which the fungus could cause decline and death of the tree. These included: (1) production of a toxin, (2) plugging of tracheids by fungal mycelia, (3) introduction of air bubbles into tracheids, and (4) production of particles or compounds that block pit openings by causing tori aspiration. Any or all of the above may occur after fungal inoculation, but it has not been proven that they are responsible for death of the tree, nor does it rule out the possibility that other mechanisms are involved. It is also possible that other fungi associated with the SPB are more important in this respect than *C. minor*.

Work by Hemingway and McGraw (Hemingway and others 1977, McGraw and Hemingway 1977) and work in our laboratories has furnished evidence suggesting the involvement of fungi in overcoming tree resistance and causing death of trees. Hemingway and McGraw isolated two phenolic acids from both liquid cultures of *C. minor* and from infected tissues of loblolly pine. The compound isolated in greatest quantity was 6,8-dihydroxy-3 hydroxymethyl isocoumarin (fig. 1, Compound I), a previously unknown fungal metabolite. A lesser amount of a second compound, 6,8-dihydroxy-3-methyl isocoumarin (fig. 1, Compound II) was isolated. A third compound, 3,6,8-trihydroxy-2-tetralone, was isolated from liquid cultures, but was not detected in tissue extracts from infected pines. Our work (DeAngelis and others 1985) confirms the production of Compounds I and II in liquid cultures of *C. minor* and has shown that purified extracts from liquid cultures can greatly increase rate of water loss from seedlings when applied to cut stems.

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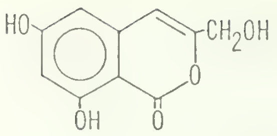
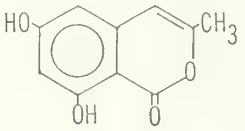


(I)

6,8-Dihydroxy-3-hydroxymethyl isocoumarin



(II)

6,8-Dihydroxy-3-methyl isocoumarin

Figure 1.--Phenolic metabolites produced by C. minor. Compound I is 6,8-dihydroxy-3-hydroxymethyl isocoumarin and Compound II is 6,8-dihydroxy-3-methyl-isocoumarin.

Specific objectives of the present work were to examine effects of isocoumarin compounds I and II on physiological processes in trees and to compare these results with those in trees undergoing attack by the SPB.

METHODS

Synthesis and Production of Fungal Metabolites

Since it was necessary to have gram quantities of the compounds for testing, it was hoped that both Compounds I and II could be synthesized. Thus far it has not been possible to synthesize Compound I, but it has been possible to obtain it by extraction and purification procedures. This work was performed by Dr. Wayne McGraw of Louisiana College in Pineville, Louisiana. He obtained the compound by extraction of inner-bark tissue of loblolly pine which had been infected with C. minor. Purification was done by liquid chromatography using procedures described by Hemingway and others (1977). Efforts to synthesize Compound I are continuing. Gram quantities of Compound II have been synthesized in our laboratories and the procedures are described elsewhere (Kendell and others 1988).

Effects of Fungal Metabolites on Transpiration

Tests were made on several occasions to determine the effects of the two isocoumarin compounds on transpiration rates in cut twigs or seedlings of loblolly pine. All tests gave similar results so only one will be described. Both compounds were administered at a concentration of 125 ppm. This concentration was chosen based on preliminary tests of concentration effects. Compound I is soluble in distilled water at 125 ppm, but Compound II is not. The pH of the water was adjusted to 10 in order to get Compound II into solution.

To minimize variation, all test material came from a single 12-year-old loblolly pine. Cuttings were obtained from a branch in the mid-portion of the crown, immediately placed in water, and transported to the laboratory where they were recut and placed in 125 ml plastic Erlenmeyer flasks, each containing 110 ml of test solution. Cuttings were randomly assigned to treatment and control. Flasks were sealed around the stem using Parafilm. Cuttings were placed in a controlled environment room under continuous light at 51 umoles/sq.m/sec., a relative humidity range of 42-44%, and an air temperature range of 29-30° C. Transpiration rates were determined gravimetrically at 2 hour intervals for a total duration of 56 hours and were expressed as grams of water loss per hour per gram of needle dry weight. All tests and measurements were replicated four times. Average transpiration rates at two-hour intervals were plotted using an error bar of two standard deviations.

Influence of Compound I on Stomatal Aperture

Because of its influence on transpiration, two tests were conducted with Compound I to examine its influence on stomatal control. The first test was performed under the same conditions as that used for the transpiration work. Relative stomatal aperture was measured using the pressure-infiltration technique of Fry and Walker (1967). Stomatal aperture was measured at 0, 6, 12, 24, 30, 36, 48, and 54 hours after treatment. The second test was done to compare the effects of Compound I to compounds and treatments known to have a marked effect on stomatal aperture. In addition to Compound I at 125 ppm the other treatments used were water (control), .1M potassium nitrate, and freezing temperatures for 10 and 25 minutes. Potassium nitrate is known to cause opening of stomates, whereas freezing temperatures cause stomatal closure (Meidner and Mansfield 1968). Loblolly pine needle fascicles were incubated in test tubes containing the test solutions. Freezing was accomplished in a laboratory freezer at -16° C. Relative stomatal aperture was determined after 19 hours of treatment. Needles were randomly assigned to the different treatments and each treatment was replicated four times. Treatment means were plotted using 95% confidence intervals.

Field Tests of Beetle-Infested Trees

Several field tests were conducted to observe the "time course" of changes in physiological processes in beetle-infested trees and to compare these changes to those occurring in seedling material exposed to the pure isocoumarin compounds. One test, replicated on three separate occasions, was designed to observe changes in oleoresin pressure, oleoresin flow, xylem water potential, and stomatal aperture in trees undergoing mass attack by the SPB. Seven beetle-infested trees and 5 control trees which were 12-14 inches in diameter were used in the tests. Oleoresin pressure and flow were measured at heights of 5, 10, and 20 feet using procedures similar to those described by Hodges and others (1977). Flow was measured at 4 and 24 hours after wounding. Xylem water potential was determined using the pressure bomb technique on small twigs from the upper part of the tree crown. Stomatal infiltration pressure (Fry and Walker 1967), a relative measure of stomatal aperture, was determined on needles from the same twigs used for xylem water potential measurements. Time intervals varied, but observations of water potential and stomatal aperture were most often made at hourly intervals from early morning to late afternoon.

A second test was conducted on four large loblolly pine trees (about 65 feet tall) to confirm observations on changes in oleoresin flow after mass attack by the SPB and to observe differences in flow with height on the stem. Flow was measured for a 4-hour period from a one-inch wound produced with a circular punch. Flow rate was measured before beetle attack on each tree and at one- or two-day intervals after attack by the SPB.

RESULTS AND DISCUSSION

Influence of Metabolites on Tree Processes

Transpiration.--The influence of Compound I on water loss from detached branch terminals is depicted in figure 2. Rates of transpiration from branches in distilled water (control) and in 125 ppm solutions of Compound I were similar for about 24 hours, after which time the rates were significantly higher for those incubated with Compound I. In both treatments, rate of transpiration decreased after about 24 hours in continuous light, but decline was more rapid for the controls. This pattern of transpiration is typical for detached loblolly pine terminals in continuous light. The initial increase for the first few hours represents an adjustment period after cutting. The decline in transpiration rate after 24 hours appears to be related to blockage of uptake by exudation of oleoresin on the cut surface. When branch bases are clipped every 6 hours, rate of transpiration does not decrease for at least 64 hours.

It has not thus far been possible to determine conclusively the influence of Compound II on transpiration, but our preliminary data suggests that it does not stimulate transpiration. Compound II is not soluble in distilled water. Solubility is increased by the addition of some organic solvents (e.g. acetone) or by increasing the pH of the solution with KOH. However, the solvents alone also influence water use by the branches and the alkaline solution modifies the structure of the compound.

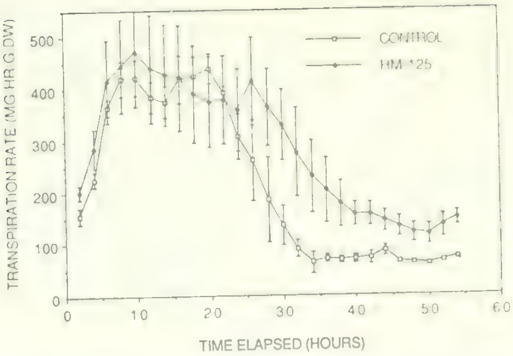


Figure 2.--Influence of Compound I on transpiration rates in branches of loblolly pine.

Stomatal Aperture.--It was hypothesized that the increase in rate of transpiration caused by Compound I could be due to its influence on stomatal control of water loss. The hypothesis was first tested in an experiment with detached branches similar to that used for measurement of transpiration. Relative stomatal aperture was determined by pressure infiltration (Fry and Walker 1967) on needles at 6-to-12 hour intervals (fig. 3). Results of this test show that after about six hours of exposure, Compound I increases stomatal aperture in needles of loblolly pine. Under continuous light stomates remain more open than those in control needles for at least another 48 hours. Stomatal movement in both control and treated needles appear to follow a cyclic rhythm even in continuous light.

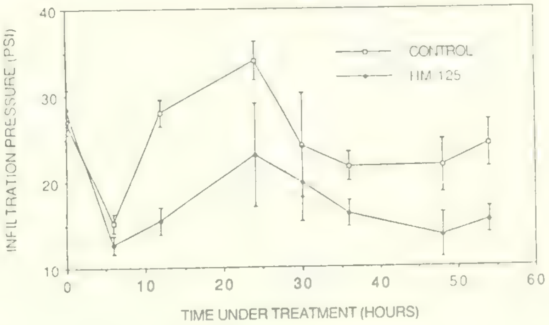


Figure 3.--Relative stomatal aperture in needles of loblolly pine as influenced by Compound I.

Substantiation of the effects of Compound I on stomatal aperture was provided by a comparison with treatments known to increase (0.1 M KNO_3) or decrease (freezing temperature) stomatal opening. Exposure to both KNO_3 and Compound I increased stomatal aperture, but Compound I appears to be more effective in that regard than is KNO_3 (fig. 4). Freezing temperature for 10 minutes caused partial closure and after 25 minutes stomates were completely closed--pressures of 45 PSI or higher caused no infiltration.

Field Tests of Beetle-Infested Trees

Oleoresin Pressure and Flow.--Following mass attack by the SPB, both pressure and flow of oleoresin decreased rapidly (table 1). Within the attack zone, pressure often decreased to zero (one

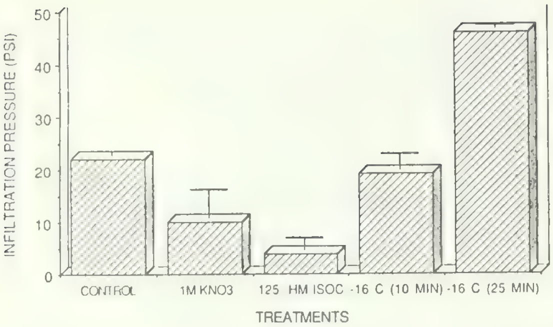


Figure 4.--Comparison of Compound I with other treatments known to influence stomatal aperture.

atmosphere) within 2 or 3 days and flow often completely ceased after 2-4 days. Data for table 1 are from a single test conducted in June and July, 1988, but several other tests gave similar results.

Table 1. Changes in oleoresin exudation pressure and flow with time after beetle attack. Values are averages for three trees.

Days Before or After Attack	Oleoresin Pressure (Atmospheres)		Oleoresin Flow (Ml/4 Hours)	
	Control	Infested	Control	Infested
-1	4.7	5.6	2.5	2.0
+1	4.1	1.6	2.5	0.6
+2	8.7	1.3	2.5	0.3
+3	5.0	--	1.8	0.5
+4	7.5	1.0	1.5	0.0

Decreases in flow and pressure occurred above the attack zone, but appeared to be less severe. A separate test designed to more closely examine the relationship between SPB attack and flow at different heights on the stem revealed that oleoresin flow declined rapidly in infested trees even at heights of at least 20 feet above the attack zone (table 2). In this test the infested zone extended from about 3 feet to about 20 feet on the second day and up to about 25-30 feet on the fourth, fifth, and sixth days. This rapid decrease in oleoresin pressure and flow no doubt has implications in terms of tree resistance and the ability of the beetle to successfully attack the tree.

Effects on Stomates and Xylem Water Potential.--As xylem water potential decreased from dawn to mid-day there was a corresponding decrease in stomatal aperture as indicated by an increase in infiltration pressure (fig. 5). This pattern was typical for control trees on clear days and it illustrates the dual influence of light and water potential on stomatal movement. In the early morning hours--to about 8 a.m.--stomatal aperture was controlled primarily by light. On most clear days maximum stomatal opening did not occur until about 8 a.m. After that time stomatal closure began and the stomates seemed to respond strongly to changes in plant water potential. A similar relationship between water potential and stomatal movement has been observed for other species (Chambers and others 1985, Running 1976, Teskey and others 1984) and the water potential at which stomatal closure was initiated is similar to that reported for seedlings of loblolly pine (Teskey and Hinckley 1986, Teskey and others 1986).

Table 2. Changes in oleoresin flow with stem height after beetle attack.

Days Before or After Attack	Height on Stem (Feet)				
	5	10	20	30	40
	Oleoresin Flow-Ml/4 Hours				
-1	2.90 (1.35)	2.07 (0.72)	1.33 (0.50)	1.37 (0.50)	1.50 (0.56)
+2	0.23 (0.23)	0.37 (0.37)	0.00	0.23 (0.09)	0.43 (0.12)
+3	0.00	0.00	0.00	0.10 (0.06)	0.23 (0.12)
+4	0.00	0.00	0.00	0.20 (0.06)	0.47 (0.09)
+5	0.00	0.00	0.10 (0.10)	0.23 (0.15)	0.40 (0.15)
+6	0.00	0.00	0.00	0.20 (0.10)	0.73 (0.22)

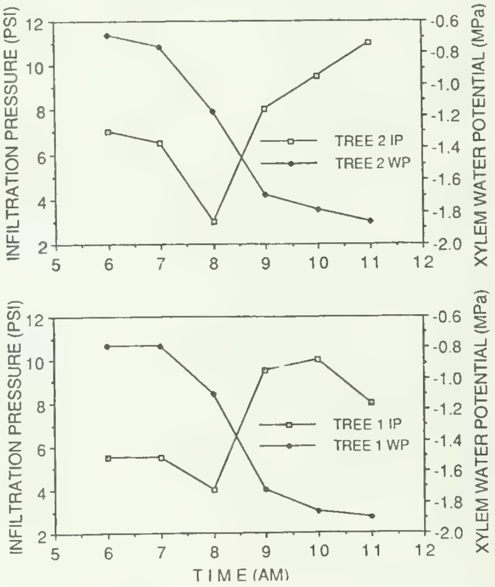


Figure 5.--Changes in xylem water potential and stomatal infiltration pressure (stomatal aperture) in loblolly pine trees during the morning hours on a sunny day.

Tests conducted in both 1986 and 1988 indicate that attack by the SPB influences stomatal opening in needles of loblolly pine as well as xylem water potential. Data for 1986 (table 3) were collected from trees subjected to a heavy mass attack at the edge of an expanding SPB spot. Soil moisture was adequate during the test period, but drying conditions were good with no rainfall. In 1988 (table 4), the beetle attack was much lighter and was induced by beetles from infested bolts placed

Table 3. Influence of beetle attack on stomatal aperture and stem water potential in loblolly pine--1986 data.[1]

Days After Attack	Stem Water Potential (MPa)		Stomatal Infiltration Pressure (PSI)	
	Control	Infested	Control	Infested
1	-1.90	-1.52	10.00	10.90
2	-1.50	-1.80	12.75	12.50
3	-1.27	-1.27	11.33	10.88
4	-1.83	-2.22	15.83	14.17
5	-0.73	-0.98	14.67	10.25
8	-1.00	-3.12	9.83	6.19
9	-1.43	-4.08	11.83	8.32
12	-2.13	-6.14	15.67	5.18

[1] Two infested and one control tree was used. Measurements were made at mid-morning (10:00-10:30 a.m.) and are the average for three determinations on each tree.

at the base of the trees. Soil moisture was lower than in 1986, but frequent rains and cloudy weather occurred during the test period so that drying conditions were less severe.

Table 4. Influence of beetle attack on stomatal aperture and stem water potential--1988 data.[1]

Days After Attack	Stem Water Potential (MPa)		Stomatal Infiltration Pressure (PSI)	
	Control	Infested	Control	Infested
1	-2.07	-1.97	7.0	9.5
2	-1.90	-1.86	8.0	11.0
3	-1.86	-1.66	6.0	5.5
4	-1.79	-1.55	11.5	6.0
7	-1.90	-1.90	6.4	5.2
8	-1.66	-1.55	9.0	8.0
9	-1.62	-1.62	13.5	10.0
11	-1.17	-1.28	13.0	3.5
15	-1.07	-1.38	13.0	4.0
18	-1.79	1.72	13.0	5.0
22	-1.55	-1.59	9.0	6.0
30	-1.72	-1.86	7.0	9.0
38	-2.03	-2.21	6.5	19.5
42	-2.100	-3.03	8.0	40.0

[1] Measurements were made at mid-day (12:00-12:30 p.m.) and are the average of two determinations for each tree.

Even with these differences between years the patterns of change in stomatal aperture and xylem water potential were basically the same. In 1986 stomatal aperture was about the same in control and infested trees until about the fifth day of attack after which stomatal aperture at mid-morning was much greater in infested trees, at least through day 12. Xylem water potential was not influenced by beetle attack until about the eight day after which mid-morning potentials were much lower in infested trees than in control trees.

In 1988 (table 4), consistent and large differences in stomatal aperture did not occur until about 9 days after attack. Mid-day apertures were then much greater in infested trees through day 22. At day 30 and thereafter, mid-day closure of stomates was obvious in the infested trees. This last time period corresponds to the time when xylem water potential began to decrease and when the first color change was observed in the foliage of infested trees. There appeared to be no difference in xylem water potential between control and infested trees for at least 22 days after initial beetle attack.

In the above tests the mid-morning or mid-day values for xylem water potential covered the range given for beginning of stomatal closure to complete closure, e.g. 0.7 to >2.0 MPa (Teskey and others 1986). However, complete closure apparently did not occur except in trees infested for more than 30 days (table 4). Also, there was no detectable correlation between water potential and infiltration pressure for these mid-day readings. One thing which does appear obvious is that in infested trees stomates can remain open even at very low xylem water potentials.

CONCLUSIONS

At least one of the phenolic compounds (Compound I) produced by C. minor appears to increase rates of transpiration in loblolly pine. The indications are that this occurs as a result of a decrease of stomatal control of water loss in infested trees. Of special interest in this respect is the slowness with which moisture stress develops in these trees even though transpiration is increased. This observation seems to indicate that water transport in the stem is not markedly affected at least in the early stages of beetle attack. However, large reserves of water in the bole of the tree could also ameliorate the effects of increased transpiration. Although moisture stress does not develop as rapidly as at first expected, the increased water loss over time is likely to be a major factor in desiccation of the foliage and eventual death of the tree.

Oleoresin flow and pressure decrease very rapidly in SPB infested trees, thus decreasing resistance to beetle attack. It has not been possible thus far to explain the mechanism(s) responsible for this rapid decrease, but it is now possible to eliminate several hypotheses about how the beetle is able to overcome tree resistance and kill the tree. As noted above, it is obvious that there is no rapid increase in moisture stress in infested trees either from excessive water loss, introduction of air bubbles or blockage of the transport system (Anderson 1960). Thus, the decrease in resin flow is not the result of a rapid increase in moisture stress. These factors may later contribute to the death of the tree, but are not responsible for the initial decrease in resistance. One possible explanation for the rapid decrease in flow is a decrease in turgor pressure of the epithelial cells surrounding the resin ducts. This could result from toxic effects of compounds produced by C. minor or other fungi.

The emphasis in the present work is on the influence of compounds produced by C. minor on tree physiology. It appears that some of these compounds may have an influence on tree physiology and decrease resistance to the SPB, but recent work (Bridges 1985, Bridges and Perry 1985, Bridges and others 1985) indicates that C. minor is not always present in SPB-infested trees and may not be necessary for beetle development. However, several other species of fungi are associated with the SPB and they may produce the same or similar compounds with similar effects on the tree.

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EFFECTS OF PREVIOUS STAND MANAGEMENT ON MORTALITY FOLLOWING GYPSY MOTH DEFOLIATION: PRELIMINARY RESULTS[1]

Kurt W. Gottschalk[2]

Abstract.--Oak-hickory forest stands were sampled for tree mortality using a series of temporary plots. Stands were classified by gypsy moth defoliation and by thinning treatment timing. Thinning of forest stands does accomplish its goal of reducing mortality in undefoliated stands; however, the effect is not clear when stands are defoliated.

INTRODUCTION

Foresters in central Pennsylvania observed that mortality following gypsy moth defoliation was higher in managed stands than in unmanaged stands. If this observation were true, proposed silvicultural treatments for minimizing the impact of gypsy moth (Gottschalk 1987) may increase the impacts. This study was conducted to test the hypothesis that there was no difference in mortality between managed and unmanaged stands.[3] The answer to this question is critical to the future development of silvicultural prescriptions for minimizing the impact of gypsy moth.

Four hypotheses were formulated to determine how thinning treatments might increase mortality following gypsy moth defoliation. The first is the concentration theory. In a thinned stand, the gypsy moth defoliation and mortality are concentrated on the crop trees left after a thinning; while in an uncut stand defoliation and mortality are dispersed across all of the trees. There is also less foliage present immediately after a thinning, so equal gypsy moth populations may cause more damage in a thinned stand.

The second hypothesis is the managerial perception theory. The amount of mortality in thinned--residual basal area (ba) of 60 sq. ft. per acre--and unthinned--ba of 100 sq. ft. per acre--stands could be equal on an absolute basis--20 sq. ft. ba--but very different on a relative basis--20 percent (20/100 sq. ft. ba) in the uncut but 33 percent (20/60 sq. ft. ba) in the thinned. If mortality is equal on a relative basis (20 percent), then it would be greatly different on an absolute basis--20 sq. ft. ba in uncut (0.2 X 100 sq. ft. ba) and 12 sq. ft. ba in thinned (0.2 X 60 sq. ft. ba). The method used to measure mortality influences the forester's perception of the stand. Twenty percent mortality in an uncut stand does not appear too bad and the stand is still manageable. However, 20 percent mortality in a thinned stand appears devastating and the stand now may be drastically understocked and in need of regeneration.

The third hypothesis is the secondary organism-abundance theory. Most mortality following gypsy moth defoliation comes from secondary organisms that invade and kill the stress-weakened tree. Thinning produces dying root systems and logging damage to residual trees that increase the populations of the two most common secondary organisms: the shoestring root rot, Armillaria spp., and the twolined chestnut borer, Agrilus bilineatus. With larger populations present at the time of defoliation, more mortality results.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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[3] The author acknowledges the assistance of David Feicht, W. Russ MacFarlane, Lynn Entwistle, Sandra Fosbroke, and Mark Mitchell in field data collection, data analysis, and preparation of graphics. The assistance of Wilbur Wolfe, Glatfelter Pulp Wood Company, and Sam Cook, Pennsylvania Bureau of Forestry, in the selection of stands and John Quimby, Pennsylvania Bureau of Forestry, in obtaining defoliation records is greatly appreciated.

The timing of cutting relative to defoliation is the key to the final hypothesis, the logging stress hypothesis. Thinning produces logging wounds, exposed roots, soil compaction, crown breakage, and new environmental conditions. This logging activity stresses the trees and may result in lower vigor for several years. The residual trees also change their growth patterns following thinning. They expand their crowns and root systems and may be more vulnerable to attack during this period. Data showing this effect were published for southern pines (Nebeker and others 1983). If a stand is defoliated during the period before it recovers from thinning-imposed stresses, more mortality may occur than in uncut stands or thinned stands that have recovered. Estimates of the time required to recover from this stress range from 1 to 3 years or even as long as 5 years for slower responding oaks (Graney 1987).

OBJECTIVES

The objectives of this study were twofold: 1) to determine if past management practices, especially thinnings, change the tree mortality when the stands are subsequently defoliated by the gypsy moth and 2) to determine if the timing of these cutting treatments relative to defoliation changes the mortality response. Results should indicate if the field observations are true and why.

METHODS

A factorial design with time-of-cutting treatment as one main effect, and defoliation class as the other, was used (table 1). Analysis of variance and individual contrasts were used to test specific hypotheses. Each cell in the design matrix was filled with two to four uniform forest stands or management units ranging from 10 to 90 acres (table 2). Study sites were selected in central Pennsylvania in the Ridge and Valley Physiographic Province on state forest and Glatfelter Pulp Wood Company lands. Stands were identified by the timing of cutting treatment through landowners' records. Only stands that contained greater than 50 percent oak (by basal area including dead trees) at the time of measurement were included. Defoliation intensity and frequency were delineated using either color infrared optical bar photography or aerial sketch maps. Identified stands were classified by treatment and defoliation history and placed in the matrix.

Table 1.--Classifications used for treatments in two-way factorial design

Class	Cutting treatment timing
	--relationship to defoliation or measurement--
1	Uncut stands
2	Thinned 1-3 years before
3	Thinned 4-6 years before
4	Thinned 7-10 years before
5	Thinned 10-15 years before
6	Thinned >15 years before
7	Thinned 1-3 years after

Class	Defoliation history
1	Undefoliated (none >30% in any year from 1979-1985)
2	Defoliated (≥1 year moderate--30-60% or heavy--60-100% from 1979-1985)

Table 2.--Number of stands and total acreage measured in each classification cell

Cutting treatment	Defoliation history	
	Undefoliated	Defoliated
Class 1	3 stands 70 acres	3 stands 162 acres
Class 2	2 stands 50 acres	3 stands 133 acres
Class 3	3 stands 101 acres	4 stands 134 acres
Class 4	3 stands 145 acres	2 stands 52 acres
Class 5	3 stands 101 acres	2 stands 55 acres
Class 6	0 stands 0 acres	3 stands 127 acres
Class 7	Not applicable	3 stands 117 acres
Subtotal	14 stands 467 acres	20 stands 780 acres
Total	34 stands 1247 acres	

Each stand was sampled using 10-factor variable-radius plots. A minimum of 15 plots were taken per stand, with an additional plot for each 8 to 10 acres over 20 acres. Additional plots were added, as necessary, to achieve a 90 percent confidence limit within 10 percent of the mean. Plots were laid out on systematic transects throughout the stands. Data were recorded using the SILVAH data collection protocol for all live and standing dead trees larger than 1" dbh. Information collected included tree species, dbh (in 2" classes), tree quality, and tree vigor (live or dead). Regeneration plots were measured also. Stand summaries were computed using the SILVAH computer program (ver. 2.3, Marquis and others 1984).

Mortality is defined and calculated as a percent by taking basal area of standing dead trees divided by the total basal area of all live and standing dead trees multiplied by 100. By using a percentage of basal area, the second hypothesis can be tested by looking at differences in relative mortality. Stand summaries or means were used as variables in statistical analyses.

RESULTS

Mortality in uncut, undefoliated stands was 12.1 percent, while in thinned, undefoliated stands it ranged from 3.6 to 7.2 percent. Mortality in uncut, defoliated stands was 30.9 percent, while in thinned, defoliated stands it ranged from 8.4 to 48.5 percent (table 3). Significant differences occurred between defoliated and undefoliated stands in cutting treatment classes 1, 3, and 4, but not in classes 2 and 5 (table 3). Individual contrasts between treatment classes within defoliation classes showed highly significant differences for the undefoliated stands (table 4). For the defoliated stands, only class 7, the postdefoliation cutting treatment, had significant differences.

Table 3.--Mortality of oak-hickory stands and independent t-tests of defoliated versus undefoliated classes within cutting treatment classes

Cutting treatment	Defoliation history Undefoliated	 Defoliated	T-test
	--percent of basal area/acre--		--t(>T)--
Class 1	12.1	30.9	.001
Class 2	4.1	42.2	.187
Class 3	3.6	37.6	.007
Class 4	4.3	29.9	.000
Class 5	7.2	17.1	.106
Class 6	---	48.5	---
Class 7	---	8.4	---

Analysis of variance of two-way unbalanced design

Source	df	Mean square	F-ratio	P(>F)
Cutting treatment	6	438.483	4.898	0.002
Defoliation history	1	2946.291	32.910	0.000
Error	26	89.526		

Table 4.--ANOVA table and individual contrasts for comparing cutting treatments within defoliation classes

Analysis of variance

Source	df	Mean square	F-ratio	P(>F)
Undefoliated stands				
Between cutting treatment classes	4	36.677	11.917	0.001
Error	9	3.078		
Defoliated stands				
Between cutting treatment classes	6	529.282	3.783	0.027
Error	11	139.896		

Individual contrasts

Contrast	Defoliation class Undefoliated	 Defoliated
	--P(>F)--	
Class 1 vs. all managed	0.001	0.959
Class 1 vs. class 2	0.001	0.327
Class 1 vs. class 3	0.000	0.504
Class 1 vs. class 4	0.000	0.925
Class 1 vs. class 5	0.007	0.226
Class 1 vs. class 6	---	0.101
Class 1 vs. class 7	---	0.040
All managed vs. class 7	---	0.005

Because defoliation effects seemed so much stronger than treatment effects in defoliated stands, I reanalyzed the data from defoliated stands by defoliation intensity and frequency (table 5). When the stands are reclassified in this way and cutting treatment is ignored, then a highly significant linear pattern is evident (table 6, fig. 1). As defoliation intensity and frequency increases, mortality increases.

Mortality rates were highest in the pole size class in undefoliated stands, while defoliated stands had greatest mortality in the small, medium, and large sawtimber-size classes (fig. 2-6).

Table 5.--Classifications used for defoliation history only

Class	Defoliation frequency and intensity
1	1 year of moderate (30-60%)
2	1 year of heavy (60-100%)
3	1 year of moderate + 1 year of heavy
4	2 years of heavy
5	3 or more years of heavy

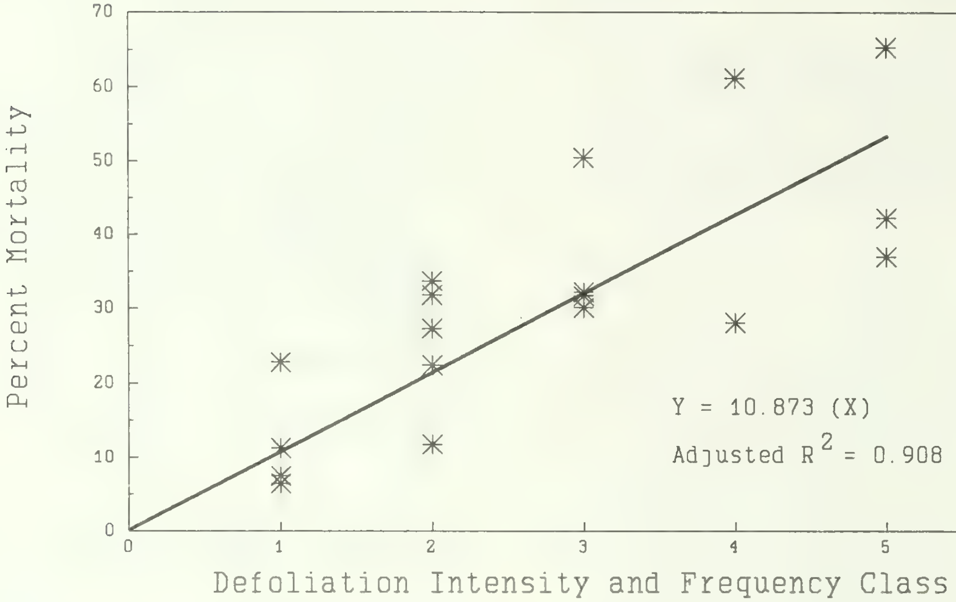


Figure 1.--Regression of reclassified defoliation versus percent mortality.

Table 6.--Mortality of oak-hickory stands by reclassified defoliation history and ANOVA of defoliation frequency and intensity classes

Defoliation history	Mortality
	--percent of ba/acre--
Class 1	12.0
Class 2	25.4
Class 3	36.1
Class 4	44.7
Class 5	48.2

Analysis of variance

Source	df	Mean square	F-ratio	P(>F)
Class	4	740.276	5.488	0.008
Error	13	134.880		

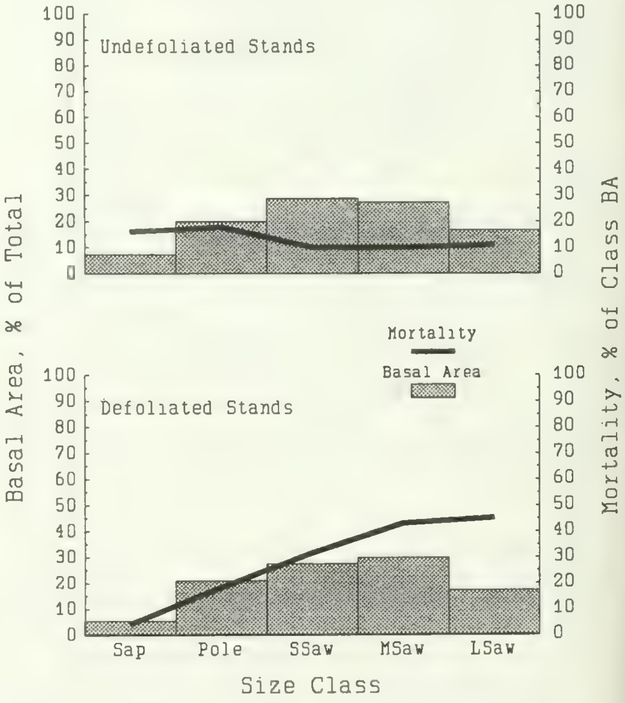


Figure 2.--Size-class distribution and mortality by size class in uncut stands.

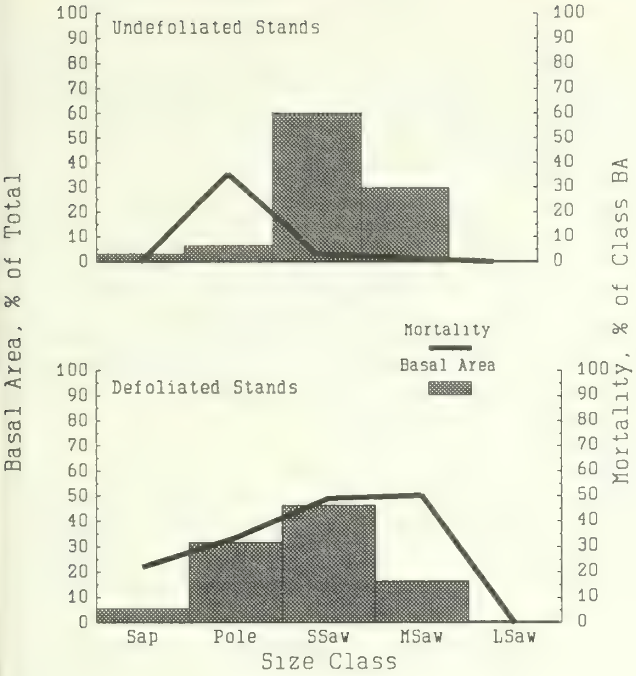


Figure 3.--Size-class distribution and mortality by size class in stands thinned 1 to 3 years before defoliation or measurement.

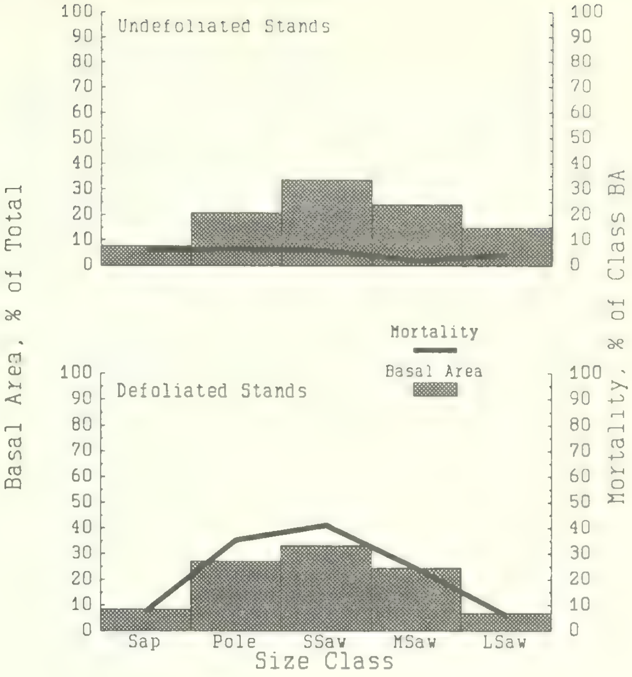
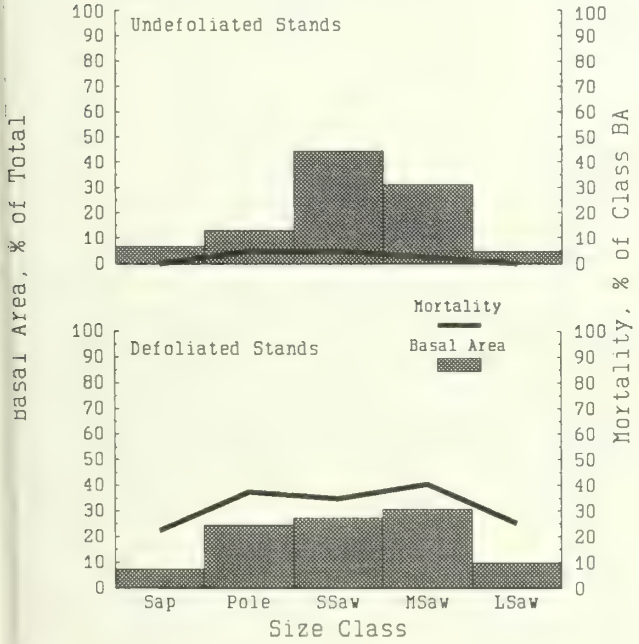


Figure 5.--Size-class distribution and mortality by size class in stands thinned 7 to 10 years before defoliation or measurement.



igure 4.--Size-class distribution and mortality by size class in stands thinned 4 to 6 years before defoliation or measurement.

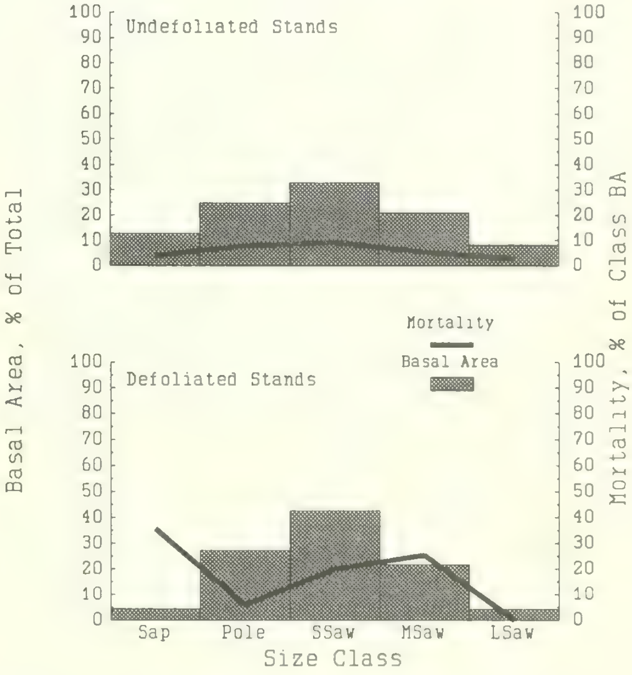


Figure 6.--Size-class distribution and mortality by size class in stands thinned 10 to 15 years before defoliation or measurement.

DISCUSSION

More larger trees die in defoliated than in undefoliated stands. Smaller, weaker trees die as competition becomes intense in undefoliated stands. Defoliation weakens larger trees, making them susceptible to secondary mortality agents, and results in death of many larger trees. Mortality of small trees does not decrease in defoliated stands, but the increases in pole-size mortality are masked by the larger increases in sawtimber-size mortality.

Mortality rates in undefoliated stands show the benefit of thinning in reducing mortality. The tendency for mortality to increase in cutting class 5 suggests that these stands are approaching the point where another thinning is needed. However, since these data are from separate stands and not true chronological series, the increase in mortality in cutting class 5 undefoliated stands could be due to sampling variation. Defoliation overshadows this pattern. Defoliated stands had higher mortality than undefoliated stands, but due to high variability there was no definitive pattern of cutting treatment that changed the mortality relative to uncut stands. This result does not support the casual observations of foresters. One potential reason for the lack of significance in defoliated stands may be the variation in defoliation between stands.

The reclassification by defoliation intensity and frequency does indeed show the importance of variation in these factors in determining mortality. Many of the stands in a thinning treatment cell had the same defoliation pattern, preventing its use as a covariate. To avoid this confounding problem and high variability, additional stands were measured during 1988 to expand the defoliated series into several combinations of intensity and frequency. When analyzed, this expanded sampling design should allow a better evaluation of the effect of cutting treatments on mortality.

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SILVICULTURAL IMPLICATIONS OF FACTORS ASSOCIATED WITH OAK DECLINE IN SOUTHERN UPLAND HARDWOODS[1/]

Dale A. Starkey and Steven W. Oak[2/]

Abstract -- Recent surveys of southern upland hardwood forests have revealed widespread oak decline and mortality that is highly variable in severity. Several site and stand factors were found associated with greater mortality but relationships were not always clear. Decline and mortality were associated with older, sawtimber-sized stands. Red oak species (especially black and scarlet oaks) were most often damaged; highest mortality levels were associated with (but not limited to) ridge or upper slope topographic positions, shallow, rocky soils and low to average site indices (≤ 70). A general classification of mortality risk can be accomplished by examination of the factors mentioned above, and others like drought and defoliation history. Preventive or remedial silvicultural treatments may be useful for reducing the effects of oak decline, and management objectives may need to be modified to avoid its consequences. These may include thinning early in stand history to reduce future competition-induced stress and to favor less susceptible species; reducing rotation age; regenerating other species and the control of defoliating insects.

INTRODUCTION

Oaks comprise the most important group of upland hardwood trees in the eastern United States. They are widely distributed, abundant on a variety of sites, have relatively high timber values and contribute substantially to wildlife habitat quality and recreational opportunities. Oak decline is the most widespread, common, and perhaps complex disease problem of this group. Dieback and mortality occur in varying degrees causing loss in timber volume, growth, wildlife and recreational values.

Episodes of oak decline in the eastern U.S. have been reported since the early 1900's (Balch 1927) up to the present time. Cases have been reported from Arkansas (Rhodes and Tainter 1980, Lewis 1981, Mistretta et al. 1981, Bassett et al. 1982, Yeiser and Burnett 1982), Connecticut (Dunbar and Stephens 1975), Florida (Lewis 1981), Massachusetts (Feder et al. 1980), Minnesota (Chapman 1915, Walters and Munson 1980), Mississippi (Lewis 1981), New Jersey (Kegg 1971), New York (Long 1914), North Carolina (Beal 1926, Tainter et al. 1984), Pennsylvania (Fergus and Ibberson 1956, Staley 1965, Nichols 1968, Wargo 1977), Virginia (Beal 1926, Rauschenberger and Ciesla 1966, Skelly 1974), West Virginia (Gillespie 1956, Staley 1965) and Wisconsin (Haack and Benjamin 1982).

Oak decline is generally considered a disease complex resulting from the interaction of predisposing stress factors with disease or insect pests of secondary action (i.e. not highly aggressive or capable of individually causing severe damage or death). Predisposing agents of stress can be defoliating insects (Tryon and True 1958, Nichols 1968, Kegg 1971, Dunbar and Stephens 1975), drought (Balch 1927, Tryon and True 1958, Rhodes and Tainter 1980, Lewis 1981, Mistretta et al. 1981, Tainter et al. 1983, Tainter et al. 1984), or late spring frost (Beal 1926, Balch 1927, Staley 1965, Nichols 1968). Disease and insect pests acting in conjunction with stress agents are shoestring root rot (caused by Armillaria mellea), other root disease fungi such as Clitocybe tabescens, Corticium galactinum (Toole 1960, Filer and McCracken 1969), Ganoderma lucidum (Lewis 1981)

[1/] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-3, 1988.

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and Polyporus dryadeus (Fergus 1956), and the 2-lined chestnut borer (Agrilus bilineatus; Balch 1927, Dunbar and Stephens 1976, Cots and Allen 1980, Lewis 1981).

Trees react to stress of defoliation or prolonged drought by converting starch (stored in the roots) to sugar to support continued metabolism. This conversion is recognized by Armillaria mellea (Wargo 1972) which lives as a saprophyte on stumps and roots of dead trees and can successfully colonize living tree root systems under these conditions. Other non-aggressive root disease fungi may act similarly. The 2-lined chestnut borer preferentially attacks weakened trees (Cots and Allen 1980, Haack and Benjamin 1982). The adult oviposits in bark crevices; the larvae bore into the inner bark and create meandering galleries, partially or completely girdling the tree.

Root disease and girdling both impair the internal water and food relations in the tree generally resulting in a progressive dieback of branches from the upper and outer crown, downward and inward. Other accompanying symptoms may include chlorotic, dwarfed or sparse foliage; development of epicormic sprouts on the main bole and larger branches; premature autumn coloration; marginal leaf scorch; foliage wilt; foliage browning and death. Sudden, total tree mortality may sometimes occur with or without prior decline symptoms. Reduced shoot and diameter growth occurs in severely affected trees. While some dead trees show little evidence of prior decline, most have declined for 2 to 5 years or more before succumbing. Because of differences in the dynamics of internal water and stored food budgets (Kramer and Kozlowski 1960), physiologically mature trees may not be able to resume normal growth with the return of good growing conditions but continue to decline, while other physiologically less mature trees recover and rebuild their crowns. Patterns of decline and mortality may be easy or difficult to discern in forest stands, depending on the inciting stress factors, site conditions and species composition.

In the early 1980's, it appeared that the southern U.S. was sustaining a substantial increase in oak mortality and decline. Inquiries of federal land managers and state foresters were made in late 1984 concerning the current status of oak decline in their areas of jurisdiction. Oak decline was reported across the south from Virginia to Arkansas, with concentrations in the Appalachian and Ozark Mountains (Starkey 1985). Responses to these inquiries provided a population of damaged stands for evaluation in 1985 (hereafter referred to as "evaluation"). Additionally, three National Forest Ranger Districts were systematically surveyed in 1986-87 including both affected and unaffected areas (hereafter referred to as "survey"). The objectives of these efforts were to characterize oak decline sites with regard to species and size classes affected, the severity of decline and mortality, and site and stand factors associated with damage and to estimate the extent and severity of decline over a wide geographic area. Preliminary results from portions of this work were reported previously (Starkey and Brown 1986, Oak and Starkey 1987).

MATERIALS AND METHODS

Survey

Three National Forest (NF) Ranger Districts (RD) consisting primarily of upland oak forests were selected for survey. These were the Buffalo RD, Ozark NF, Arkansas, the Wayah RD, Nantahala NF, North Carolina and the Lee RD, George Washington NF, Virginia (fig. 1).

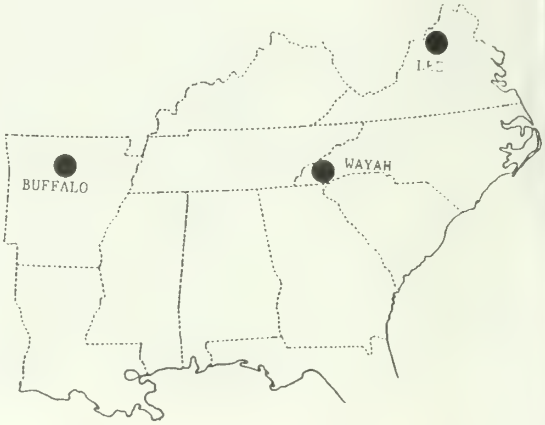

Figure 1.--Location of 3 National Forest Ranger Districts surveyed for hardwood decline.

A multi-stage survey was designed utilizing strip aerial photography, photo sample plots and field plots to determine the extent and severity of decline and mortality. Thirty-five to 55, 360 acre, square photo sample plots (about a 10% sample of RD acres) were established on each RD and each consisted of 144, 2.5 acre (approx.) cells. Stratification was done for each hardwood cell by quickly assigning it to a size (sawtimber or poletimber) and damage (1 = no dead/declining trees; 2 = 1 dead/declining tree; 3 = 2-4 dead/declining trees; 5 = 5 or more dead/declining trees) class. Detailed tree counts of dead/declining trees were performed on 678-747 cells per RD.

Field plots were located in about 30 of the counted cells per RD and consisted of 5, BAF-10 prism plots, systematically spaced within the cell. Trees 5.5" and larger were tallied and classified according to crown position and crown condition class (slight, <1/3 dieback; moderate, 1/3-2/3; severe, >2/3; dead). Site data recorded at each plot were slope, aspect, topographic position, soil depth and texture and site index (one tree per cell). Analysis of these data is in progress and only a few preliminary summaries for dominant and codominant trees are presented.

Evaluation

Thirty-eight decline sites were chosen for evaluation from the population of damaged stands reported to us. Criteria for selection included the absence of recent site disturbances (e.g., fire, logging, road construction), species composition predominantly oak, and an area uniform enough to be considered a stand-sized management unit (15-100+ acres). We attempted to achieve a dispersion of stands across the region where decline was reported (fig. 2). Surveyed stand location and number were: Virginia (11), North Carolina (4), South Carolina (3), Georgia (2), Tennessee (5), Alabama (2), Illinois (2), Missouri (2), and Arkansas (7).

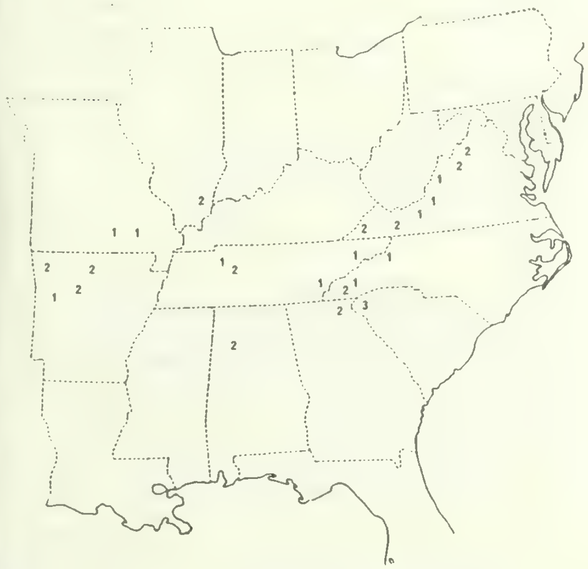

Figure 2.--Location and number of stands evaluated for oak decline severity, site and stand conditions.

Each stand was sampled with 12 systematically placed BAF 10 prism plots. Trees 5.5" and larger were tallied and classified according to crown position, and crown decline condition class (slight, <1/3 dieback; moderate, 1/3 - 2/3; severe, >2/3; dead). Stand data recorded were elevation, slope, aspect, topographic position, soil depth and texture to 24 inches, and site index. The percentage of dominant and codominant trees in the various crown decline condition classes was compared for individual species and species groups and various site factors using analysis of variance, Duncan's Multiple Range Test, and occasionally chi-square analysis. Data are presented in trees per acre rather than basal area per acre. Crown decline condition classes were combined for some analyses. Suppressed and intermediate crown classes were omitted from analyses, because dieback and mortality caused by decline cannot be separated from that caused by overstory competition in these crown classes.

RESULTS

Survey

Preliminary summaries of the survey data indicate that 27-41% of the hardwood sawtimber acres on the 3 RD's surveyed had damage levels represented by the two highest damage strata (3 and 4; table 1). Only sawtimber data are presented here since 92-99% of the area was sawtimber-size. Damage in these strata averaged about 4% of the basal area dead and increased to 6-13% when trees with advanced decline (>1/3 dieback) were added (table 2). Data analysis involving the poletimber size-class, tree species affected, site and stand factors is still in progress.

Table 1.--Estimated percent of acres in the sawtimber damage classes 3 and 4 for 3 National Forest Ranger Districts

	Percent of Acres	
Ranger District	Total Regulated	Hardwood Sawtimber
Buffalo	23	28
Wayah	27	34
Lee	41	58

Table 2.--Average percent of basal area affected or dead in sawtimber damage classes 3 and 4 for 3 National Forest Ranger Districts

	Percent Basal Area	
Ranger District	Dead	Declined and Dead
Buffalo	3.9	6.4
Wayah	3.6	12.5
Lee	4.3	13.2

Evaluation

A total of 3,623 trees were observed in the 456 plots in the 38 stands affected by oak decline. Of these, 2,810 were dominant or codominant and consisted of 84% oak (*Quercus* spp.), 6% hickory (*Carya* spp.), and 10% other species. The predominant species in the other category were maple (mostly red maple, *Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*), black locust (*Robinia psuedoacacia*), and blackgum (*Nyssa sylvatica*).

Eighty percent of the trees in oak decline areas showed decline or mortality (table 3). About 20% of these had advanced decline (> 1/3

Table 3.--Percent of dominant and codominant trees by species and crown condition on evaluated sites[1]

Crown Condition	Species							
	BLO	SCO	NRO	WHO	CHO	H	Other	All Species
Healthy	9.5	8.0	8.5	31.4	13.5	23.4	63.5	20.4
Slight	40.5	39.4	52.5	38.6	60.6	47.6	22.9	42.8
Advanced(*)	16.5a[2]	29.7b	28.6b	18.5a	21.3ab	17.0a	10.0	20.2
Dead(**)	33.5a	22.9a	10.4b	11.5b	4.6b	12.0b	3.6	16.6
TOTAL	100	100	100	100	100	100	100	100

[1] Species with > 100 observations (> 5% of the stocking).

[2] Significance applies within but not among crown condition classes. Values followed by different letters are significant at the .01 level (**) or .05 level (*), as indicated for the crown condition class. Where no letters appear, F statistics were not significant and no Duncan's was performed.

crown dieback; moderate and severe classes combined) and 17% of the stocking was killed.

Stand Factors

Species Composition.-- Evaluated oak decline stands averaged 22% scarlet oak (*Q. coccinea*), 17% black oak (*Q. velutina*), 15% white oak (*Q. alba*, and 12% chestnut oak (*Q. prinus*). Hickories accounted for 7% of the stocking with the remainder being other species.

Species in the red oak group (ARO) were much more frequently damaged than those in the white oak group (AWO; table 4). The percentage of healthy red oaks was one-third that of white oaks, while the percentage of dead red oaks was three times that of white oaks. These differences were highly significant (*P* = .01). Advanced decline in the two was not statistically significant.

Table 4.--Percent of dominant and codominant red and white oak trees in various crown condition classes

Crown Condition	Red Oaks	White Oaks
Healthy	7a[1]	24b
Slight	44a	48a
Advanced	24a	19a
Dead	24a	9b

[1] Significance applies within crown condition class. Values followed by different letters are significantly different at the p = .05 level according to analysis of variance.

Among individual oaks, black (BLO) and scarlet (SCO) oaks sustained the highest mortality levels (34 and 23%, respectively), followed by white oak (WHO), northern red oak (NRO), and chestnut oak (CHO; table 1). Among non-oak species, hickories (H) were most severely affected (12% mortality). Advanced decline was worst in scarlet, northern red (*Quercus rubra*), and chestnut oaks.

Age.-- Evaluated stands were mainly sawtimber-sized with ages ranging from 50 to 110 years. Most were in the 60- to 80-year-old age class (31 of 38 stands). A few poletimber-sized stands of advanced age were encountered. Since our sampling did not include a wide range of ages, no firm conclusion can be drawn regarding age and decline. However, we limited our sampling to known areas of decline and can infer that damage is probably more common and severe in these older age and larger size classes. We received no reports of young poletimber-sized stands being affected.

Basal Area.-- Basal area per acre (all crown classes) of evaluated stands averaged 87 square feet and varied little among stands (range from about 70 to 110 square feet). Several statistical analyses were performed on plot basal areas versus advanced decline and mortality but no significant relationships were detected. A representative portion of these data is presented in table 5.

Site Factors

Associations were explored between damage severity and topographic position, slope class, aspect, soil texture, soil depth, and site index.

Topographic Position.-- Decline and mortality were present on all topographic position categories (ridge, slope, bench, terrace, and bottom), but there were adequate numbers of observations on only slope and ridge positions. Statistically significant differences occurred for mortality with ridges exceeding slopes (table 6). The inverse relationship was present for advanced decline but was not significant.

Table 5.--Average percent of trees in various crown condition classes and basal area categories

Basal Area (Sq. Ft. per Acre)	Advanced	Dead
<70	17[1]	17
70-80	17	17
90-100	13	21
110-120	12	18
>120	18	19

[1] Values in columns are not significantly different.

Table 6.--Percent of dominant and codominant trees in various crown condition classes for various site factors associated with affected stands

Site Factors	Advanced	Dead
Topographic Position		
Ridge	17a[1]	20a*
Slope	20a	16b
Slope Class		
0-20%	15a	20a*
21-40%	24a	12b
>41%	19a	5c
Soil Texture		
Stony/Gravelly	9a**	26a**
Other	25b	12b
Soil Depth		
<18"	14a*	25a*
>18"	27b	8b
Site Index		
<65	13a*	22a*
65-75	21ab	16ab
>75	27b	10b

/ Values in each group within a column are ignificantly different at the p = .05 (*) or = .01 (**) level when followed by a different etter (analysis of variance or Duncan's ltiple Range Tests).

Slope Class.-- The effects of slope class were examined only for plots with a slope topographic position (65% of all plots). Overall, the percentage of trees in the healthy plus slight crown condition increases with increasing slope, while there is a concomitant decrease in mortality (table 6). However, significant differences exist only for the precent mortality.

Aspect.-- Associations of damage with aspect were also examined only for plots with a slope topographic position. While no statistically significant differences existed, overall damage (advanced decline plus dead) was greatest in west to north aspects, least on northeast and east aspects, and intermediate in southeast to southwest aspects (fig. 3).

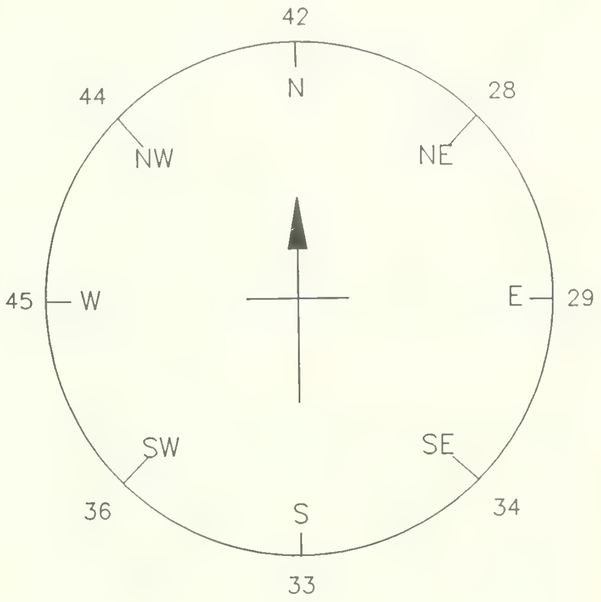

Figure 3.--Average percent of dominant and codominant trees in the advanced and dead crown classes on various aspects.

Soil Texture.-- Two broad soil texture categories were established because of the small number of observations in many individual classes. Stony or gravelly soils had significantly greater mortality than other soil textures (table 6; 26 vs. 12%; P = .01). The converse was true for advanced decline (9% for stony or gravelly soils, 25% for other textures). The healthy plus slight crown condition classes were approximately equal.

Soil Depth.-- Soil depth classes were also combined into two classes, shallow (< 18" deep) and deeper soils (>18" deep). Results were similar to those for soil texture. Shallow soils had higher mortality levels than deeper soils (25 vs. 8%) while converse was true for advanced decline (27 vs. 14%; table 6). Both of these relationships were highly significant (P = .01).

Site Index.-- All the factors previously discussed contribute to site index, the most common measure of site productivity. Most individual factors associated with low site indices (i.e., shallow, stony soils on ridges) had the highest levels of mortality. This was also the case when site index was analyzed (table 6). Mortality was 22% of stocking on low site indices (< 65 ft. at age 50) and only 15% on the highest site indices (> 75 ft. at age 50). Advanced decline was higher on productive sites (28%) than on the least productive (18%). Both of these relationships were significant.

Risk Classification

The association of site and stand factors with decline severity can be used to construct a rudimentary classification system for mortality risk due to oak decline (fig. 4). We made no attempt to weight each of the individual site and stand factors according to the strength of the association with decline severity. However, of the factors studied, aspect was not statistically correlated and should be considered the weakest component of the classification. Other data analyses (not presented here) indicate that some factors vary in importance among geographic areas. Quantitative risk rating systems may eventually be tailored to limited geographic areas where conditions may be more uniform.

LOW DAMAGE POTENTIAL (MORTALITY RISK LOW)		HIGH DAMAGE POTENTIAL (MORTALITY RISK HIGH)
ADEQUATE GROWING SEASON MOISTURE	<---->	ACUTE SUMMER DROUGHT (2-3 YRS. PRIOR)
NO RECENT OR REPEATED SPRING DEFOLIATION	<---->	RECENT OR REPEATED SPRING DEFOLIATION
PHYSIOLOGICALLY IMMATURE (POLE-SIZED, <50 YRS OLD)	<---->	PHYSIOLOGICALLY MATURE (SAWTIMBER, >50 YRS OLD)
COMPOSITON PREDOMINANTLY WHITE OAK GROUP	<---->	COMPOSITION PREDOMINANTLY RED OAK GROUP
HIGH SITE INDEX (>70)	<---->	LOW SITE INDEX (<70)
MESIC SITE CONDITIONS Loamy soils, few rocks Deeper (>18in) soils Coves, terraces, bottoms, lower slopes Northeast and east aspects	<---->	XERIC SITE CONDITIONS Rocky soils Shallow (<18in) soils Ridges or upper slopes South and West aspects

Figure 4.--Risk rating system for oak mortality in the southern upland hardwood region.

CONCLUSIONS AND SILVICULTURAL IMPLICATIONS

These results suggest that while decline is widespread and occurs on all types of sites, it most commonly results in high mortality levels on sites of average and lower productivity. These are defined at the extreme by ridges, gentle slopes, and shallow, rocky soil. Additionally, red oak species are more severely affected than white oak or other species. More productive sites may, however, exhibit high levels of decline and high mortality if stand conditions are conducive to it (e.g., older stands with a predominance of black and/or scarlet oaks) and if stresses are severe or persist for long periods.

The simple risk classification presented here should be of use to managers in identifying stands and sites prone to mortality and in prioritizing these for preventive or remedial silvicultural treatments. However, more information is needed to improve the accuracy of such assessments. For instance, data are needed to more accurately account for defoliation episodes by insects such as the gypsy moth. Because they tend to feed selectively on certain tree species, decline and mortality may develop differently than these results now indicate (Herrick and Gansner 1987). Also, risk rating needs to be tailored to more limited geographical areas (eg. Ozark mountains, southern and northern Appalachians). A broader range of damage intensities need to be examined to determine if decline as well as mortality can be included in the risk rating. Such data are available from the survey of three Ranger Districts and will be incorporated in future analyses.

There are several implications of these data for the management of upland hardwood forests. Obviously, severe decline and mortality make silvicultural decision-making more difficult. Three remedial options are available for mature, affected stands; no treatment, salvage, and regeneration. Carrying the stand with no treatment is a passive acceptance of the risk to further decline and mortality. Where damage is light and risk appears low, this is probably the best course of action to take. However, the species composition of severely declining stands is likely to shift away from the faster growing red oaks to the less-affected, slower growing white oaks. This may not be a problem if higher white oak compositions are desireable and adequate stocking of white oaks is present. Where white oaks are less abundant, other less desireable species will probably increase, contributing to a reduction in timber and wildlife value.

Salvaging dead and severely declined trees would capture some economic loss, but this must be weighed carefully against the possibilities of logging damage to the residual stand and an understocked condition developing if further mortality occurs. In addition, stump material (resulting from logging) contributes to the further buildup of A. mellea in the stand. While controlled studies have not been conducted, our experiences indicate that partial cuttings in declining or vulnerable stands results in accelerated decline of residuals, perhaps due to added moisture stress from soil drying, compaction or root injuries.

The decision to regenerate affected stands is a difficult one. If sufficient advanced reproduction of desirable species is present regeneration can be accomplished immediately. Where advanced reproduction is insufficient, delaying regeneration may not allow its development if the overstory seed source has been removed by mortality or impaired by decline. Also, diseased root systems may not sprout with normal vigor or frequency and undesirable understory species may outcompete oak reproduction for newly available growing space.

Silvicultural options of a preventive nature are more numerous. First, risk classification systems (as presented earlier) can be used to identify those stands or sites where mortality and decline will be most severe and target them for preventive silvicultural treatments. While weather factors such as drought or frost cannot be controlled or predicted, defoliator outbreaks can, in part, be predicted and mitigated (primarily with aerial spraying). This has been done for many years with pests such as the gypsy moth in the Northeastern U.S. As this particular pest continues to spread south, such programs will contribute to a reduction in stress, most importantly on sites and stands high risk to mortality.

Thinning (especially in younger stands) when accomplished in advance of decline or defoliation events should reduce the subsequent severity of decline and mortality by alleviating stress with improved growing conditions. As mentioned earlier, this activity may also cause damage to the residual stand and provide a larger food base for A. mellea. Therefore, thinning should be done carefully and infrequently. Timber stand improvement work is a similar option for younger, non-merchantable stands. In either case species composition can be shifted (if desired) from the more susceptible red oak species, to the less-affected white oaks and individuals of poor quality removed. This may not be a viable option in areas subject to gypsy moth efoliation as high levels of white oak enhance tand susceptibility to defoliation.

Other options (more subject to management constraints) are the adjustment of rotation ages and conversion to alternative species. On low-quality sites where mortality is more severe, a reduction in the length of the rotation might reduce the amount of mortality over a rotation, provide for regeneration at a lightly younger, more vigorous condition and allow the retention of faster-growing, less olerant, more desirable oak species. Some ites might be better managed as pine or ine-hardwood mixtures (if compatible with anagement objectives).

Though oak decline has been a recurring roblem with a long history in the east, it is ot known if the current situation represents a permanent increase in damage occurrence or severity. It is most likely, the result of climatic stress (eg. recent droughts), the relatively uniform susceptibility of the upland oak forests in the south (i.e. extensive, sawtimber-sized stands, aged 60-100+) and will dissipate before recurring again in the future. Past cutting practices, fire, woods grazing and the chestnut blight epidemic have had enormous impacts on the condition and species composition of southern oak forests. The resulting forests and species and trees we manage today may be less well adapted to the prevailing conditions than previous forests, especially under certain management regimes being used (i.e. extensive, sawtimber rotations).

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Wildlife Interactions

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RELATIVE ABUNDANCE OF SMALL MAMMALS IN YOUNG LOBLOLLY PINE PLANTATIONS[1]

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Abstract.--Trapping indices for small mammals on bedded loblolly pine (Pinus taeda) plantations, age 1-3 years, were 20.6, 18.7, and 14.0; and on herbicide site prepared plantations, age 1-4 years, were 29.9, 16.6, 14.1, and 11.3. The index was 0.22 for mature pine-hardwood forests, Kemper County, Mississippi.[3]

INTRODUCTION

Demand for wood products from southern forests has increased, and to increase wood and fiber production, public, private and forest-industry owned lands are being managed as pine (Pinus spp.) plantations. Frequently, mature pine-hardwood forests have been converted to pine plantations. Conversion includes clearcutting and site preparation by various methods.

Mechanical or chemical (herbicides) site prep methods greatly alter plant communities and change wildlife habitat conditions. Small mammals are important prey of many predators, including bobcat (Lynx rufus), gray fox (Urocyon cinereoargenteus), coyote (Canis latrans), snakes, hawks, and owls. The objective of this study was to determine the relative abundance of plantations that had been mechanically site prepared, plantations that had been chemically (herbicides) site prepared, and mature, mixed pine-hardwood forests.

STUDY AREAS

The study was conducted in the Interior Flatwoods land resource area in east central (Kemper County) Mississippi. This area has a mild climate, slope of 0-3%, acid-clayey soils, and a SI of 68 ft for loblolly pine on a 25-year base.

Mature (~60 years old) pine-hardwood forests occupied all study areas prior to establishment of pine plantations. Clearcutting involved the removal of all merchantable pine and hardwood sawtimber and pulpwood. One site prep method was mechanical and included shearing, raking, burning windrows, and bedding. The other site prep method was chemical and included mist-blowing (2-4-5-T), broadcast burning, and injection (2-4-D). All tracts were hand-planted with loblolly pine seedings at a spacing of 7 x 8 ft. Plantations varied in size from 400-600 acres.

Three plantations, age 1, 2, and 3 years, that were mechanically site prepared, and 4 plantations, age 1, 2, 3, and 4 years, that had been chemically site prepared, were used. In addition, small mammal relative abundance was studied in 3 mature pine-hardwood forests.

Vegetation on the mature forests was dominated by pine and hardwoods (Quercus spp., Carya spp.) in all strata. The herbaceous layer was sparse. Vegetation on pine plantations was primarily grasses (Panicum spp., Andropogon spp. Uniola sp.), sedges (Scleria spp., Carex spp.), forbs (Solidago spp., Ludwigia sp., Erechtites sp., Erigeron sp., Eupatorium spp., Acalypha sp., Dioclea sp.), vines (Rubus spp., Smilax spp., Rhus sp.), and hardwood brush (Perkins 1973).

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3/ Project was supported by Weyerhaeuser Company.

METHODS

Removal trapping was conducted from mid-December 1971 through late January 1972, and again in December 1972 through January 1973. Five trap lines per area were randomly located in each pine plantation (PP) and pine-hardwood forest (PHF). Trap lines began 120 ft from secondary roads which traversed PP and PHF. Each trap line consisted of 5 or 10 trapping stations, about 66 ft apart. At each station 3 traps, a Sherman live trap, a large four-way snap trap, and a small four-way snap trap were set. One trap was on the trap line, and the others were perpendicular to the line, about 10 ft from the line. Trap position was altered at each station. Total traps per line was 75 or 150.

All traps were baited with a mixture of peanut butter, oatmeal, and sardines. Traps were baited in the afternoon and were checked the next morning. Traps were rebaited and checked again a second and third day, thus the trapping period was 3 consecutive nights/days. Small mammals were removed from the traps, appropriately tagged, placed in an ice cooler, and later frozen. Subsequently, they were identified, sexed, aged, and weighed (Perkins 1973).

Total catch by species and treatment was calculated per 100 trap nights to yield a trapping index. A trap night was defined as 1 trap set for 1 night, regardless of type of trap.

RESULTS

Only 3 white-footed mice (Peromyscus leucopus) were caught in 1,350 trap nights in the PHF for a trapping index of 0.22 (Table 1). A total of 7,575 trap nights resulted in the capture of 1,399 small mammals in PP. Of these, 999 (71.3%) were cotton rats (Sigmodon hispidus), 259 (18.5%) were house mice (Mus musculus), 49 (3.7%) were white-footed mice, and 15 (1.1%) were short-tailed shrews (Blarina brevicauda). Total (all species) trapping indices were highest for the youngest PP and generally declined as PP age increased. The highest total trapping index (29.9) and the highest cotton rat trapping index (24.8) occurred on the 1-year-old PP site prepared by herbicides and fire.

Cotton rats from chemically site prepared PP averaged 90.15 (age 1), 92.14 (age 2), and 96.11 g, and those from mechanically site prepared PP weighed 82.22 (age 1) and 87.89 g (age 2). Averaged over all PP ages and site prep methods, rice rats weighed 45.36 g, white-footed mice weighed 17.01 g, houce mice weighed 13.32 g, harvest mice weighed 8.22 g, and shrews weighed 3.97 g. Sex ratio for cotton rats trapped on bedded PP was male 1.19:1.0 female and on herbicide PP was male 1.0:1.14 female.

DISCUSSION

The low trapping index in the PHF can be attributed to the comparatively sparce herbaceous vegetation, which does not support high density small mammal populations (Goertz 1964). Structure and composition of the herbaceous layer were reported to be important to small mammals (Dueser and Shugart 1978). Clearcutting and site preparation created early plant successional communities, dominated by grasses, sedges, and forbs. These pioneer plant communities were good habitat for small mammal populations, particularly cotton rats. Atkenson and Johnson (1979) found that white-footed and house mice predominated on 1-year-old but cotton rats predominated on 3-year-old loblolly pine plantations mechanically site prepared in Georgia. Total catch of all small mammals declined sharply at age 5 years. McComb and Rumsey (1982) reported more small mammals on clearcuts and herbicide treated plots as on uncut forests in Kentucky.

Small mammal relative abundance was highest at the youngest age pine plantation and decreased as pine plantation age increased. Langley and Shure (1980) found that cotton rat densities were significantly greater in natural habitat (old fields) versus planted loblolly pine plantations in the Georgia Piedmont. They thought that planting pines in old fields altered the structural nature of the understory vegetation and thus the small mammal microhabitat.

The herbicide site prep method (brown and burn) caused less disturbance to the site, compared to shearing, raking, and bedding, and the herbaceous vegetation was dense during the first growing season (Perkins 1973). Trapping index for cotton rats and total small mammals decreased as the PP became older. PP site prepared by intensive mechanical methods had less herbaceous vegetation the first year, compared to chemically site prepared PP, and the cotton rat trapping index increased slightly on bedded PP from age 1-3 years. Plant succession was rapid on PP and small mammal habitat deteriorated as pines and hardwood brush replaced the grasses and forbs.

PP are excellent feeding areas for many predators for several years. In addition to the comparatively high numbers of small mammals, PP support large numbers of rabbits (Sylvilagus spp.) (McKee 1972). Pine-hardwood forests have few small mammals and rabbits but support moderately high squirrel (Sciurus spp.) populations. Bird densities were much higher on young PP than

Table 1.--Small mammal trapping indices (catch per 100 trap nights) by species on pine-hardwood forests (PH) and loblolly pine plantations (PP), by site prep method and age (years), Kemper County, Mississippi, 1971-73.

		PP (Bedded)			PP (Mistblown-injected)			
Species	PH	1	2	3	1	2	3	4
Cotton rat	0	9.5	11.2	12.0	24.8	13.8	12.7	8.4
Rice rat	0	1.2	2.1	1.5	1.6	0.6	0.4	0
House mouse	0	8.6	4.5	0.3	2.6	1.8	0.9	0.8
White-footed mouse	0.2	1.1	0	0.2	0.8	0.1	0	2.0
Short-tailed shrew	0	0.2	0.5	0	0.1	0.4	0.1	0.1
Total	0.2	20.6	18.2	14.0	29.9	16.6	14.1	11.3

pine-hardwood forests (Perkins 1973, Darden 1980).

As PP approach canopy closure, unfavorable habitat conditions exist for small mammals and rabbits. PP should be thinned and control burned as soon as possible to reinstate a herbaceous layer and improve habitat conditions. Forest managers can plan for the best spatial and temporal distribution of different age PP. Therefore, overall habitat conditions for small mammals can be improved to provide a prey base for many predators or furbearers, as well as excellent feeding areas for hawks and owls that spend the winter in the South.

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DEER BROWSE DAMAGE EFFECTS ON CONTAINERIZED WHITE PINE SEEDLINGS [1]

Ronald L. Hay and John C. Rennie [2] [3]

Abstract.--After various greenhouse and shade-house culture treatments, dormant 15-month old containerized white pine seedlings were outplanted on a disked, old-field. Natural photoperiod in the greenhouse produced a significant height response after the first field growing season and the large container produced the largest diameter after five years. Deer browse was a problem in the third year, causing stem deformation and significant reductions in height and diameter through year five. Limited stem form recovery occurred by year five but growth of non-browsed seedlings continued to exceed all others.

INTRODUCTION

Our initial objective was to grow seven-month old containerized white pine seedlings in the greenhouse during winter and early spring, with outplanting scheduled after spring frosts were past. Unfortunately, too many seedlings failed to continue height growth and competing vegetation gained the advantage (Hay and Keegan 1982). The work reported here was a test of growth responses using dormant containerized seedlings.

White pine containerized seedlings grown in the greenhouse using culture treatments of photoperiod, media, carbon dioxide, and container size were moved to a shadehouse on June 1 at age 7 months. They remained there throughout the growing season, going dormant according to natural temperature and photoperiod stimuli. They were outplanted at Ames Plantation in Fayette County on February 1, 1983 at 15 months of age while still dormant.

These seedlings appeared similar to nursery-grown, 2-0 bareroot seedlings, e.g., they were more than one year old having received an extended growth period in the greenhouse and shadehouse, they had good root systems, and they had secondary leaf development. However, they lacked the stem height and caliper of 2-0 bareroot seedlings, which have been shown to be important in good seedling growth after outplanting (Hay and Rennie 1987).

The principal objective was to test growth of containerized white pine seedlings that had received various greenhouse and shadehouse culture treatments and which were dormant at outplanting. It was not until the third growing season when deer browse became a serious problem that we decided to also relate browse damage to seedling treatment and growth.

METHODOLOGY

Seedling Culture

Containerized white pine seedlings were grown in the greenhouse for seven months using cultural treatments of supplemental light and CO_2, four

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[3] Grateful acknowledgement is made to Ames Plantation for use of their facilities and assistance from Ames management personnel.

different growing media, and two container sizes (Hay 1981). The seedlings were then moved to shadehouse benches in 70% sunlight where they were maintained by overhead irrigation and periodic liquid fertilizer (20-20-20) throughout the growing season. Greenhouse treatments were discontinued in the shadehouse. After the seedlings were dormant they were moved to the shadehouse floor and mulched to minimize winter damage. Further irrigation was not necessary.

Outplanting

An old-field, abandoned several years previously and along an intermittent stream, was chosen. Soil was Collins fine sandy loam, a local alluvial soil considered productive for agricultural use. The site was thoroughly disked in the autumn. It was void of vegetation when the seedlings were planted on February 1. Fertilizer was not added during planting.

Since the site was uniform and there were unequal numbers of seedlings available, a completely random design was chosen. Seedlings were planted in five-tree row-plots with one meter between seedlings and three meters between rows. Greenhouse treatments were assigned at random to plot location.

Initial plot maintenance was periodic disking between rows with no attempt to control weeds within the row. After the third growing season deer browse damage was apparent so a deer repellent was applied three times during each dormant season. The repellent, an ammonium soap of fatty acids, was applied as per the label starting in November with subsequent sprays at six to seven week intervals.

Measurements and Analyses

Total seedling height and diameter at the soil surface were measured after each of the first five growing seasons. Deer browse occurrence was recorded at the end of the third growing season. Survival was recorded periodically during the first growing season in an attempt to identify any major problems with seedling mortality and to monitor height form development. Survival records were discontinued when it became apparent that seedling growth was progressing normally.

Percent of surviving seedlings in each plot after the first year was transformed with the arc sine of the square root; these data were analyzed by greenhouse treatments and first order interactions. Mean total height and mean diameter at the soil surface were calculated by plot; these means were analyzed by greenhouse treatments and first order interactions. Mean total height and mean diameter at the soil surface were calculated by plot; these means were analyzed by greenhouse treatments and first order interactions for year one to year five. Total height and diameter at the soil surface for year two to year five were analyzed by browse status. Duncan's multiple range test was applied to treatment means that were significant in the analyses of variance. Distribution of browse status and greenhouse photoperiod treatment was tested with Chi-square. All analyses were done with PC-SAS (SAS Institute Inc. 1985).

RESULTS

Greenhouse Treatments Effects

Seedling survival did not respond to 24-hour photoperiod, supplemental CO_2, media or container size during greenhouse culture. When planted at 15 months of age, all seedlings survived equally well. A few seedlings were clipped at the soil surface by rabbits, but no other survival problems occurred.

A summary of height and diameter means for greenhouse treatments is presented in table 1. After one growing season in the field those seedlings that had received natural photoperiod in the greenhouse were significantly taller than those seedlings that had received 24-hour photoperiod. There were no subsequent differences between total height means according to photoperiod treatment.

Additional greenhouse culture treatments, namely supplemental CO_2, growing media, and container size did not affect seedling total height through five growing seasons. Neither were there consistent trends among means for the CO_2 and growing media treatments. However, the larger container (Hillson rootrainer) consistently produced larger seedlings than the Fives rootrainer and the difference between means increased each growing season.

Photoperiod, supplemental CO_2, and growing media did not influence seedling diameter at the soil surface through five growing seasons. The large rootrainers produced a significantly larger seedling five years after outplanting. The trend was consistent but the difference between means was not significant until year five.

Deer Browse Effects

During the first two growing seasons deer browse was infrequent. However, Table 1.--Total height and diameter at the soil surface development for containerized white pine seedlings on the Ames Plantation without regard to deer browse damage

GREENHOUSE TREATMENT	HEIGHT					DIAMETER				
	Years after planting					Years after planting				
	1	2	3	4	5	1	2	3	4	5
Light	--Centimeters--					--Millimeters--				
24-hour	14.5b[1]	32.6	54.8	95.7	146.9	4.2	5.8	9.6	18.7	37.9
Natural	16.5a	32.7	54.2	92.5	146.7	4.0	5.8	9.7	18.4	38.1
CO_2										
supplemental	14.5	33.0	55.0	95.0	144.0	4.3	5.9	9.5	18.0	38.0
ambient	15.1	32.3	54.5	95.1	149.0	4.0	5.8	9.7	19.0	37.9
Growing Media										
pinebark:peat	15.1	34.0	54.2	95.8	148.6	4.2	6.1	9.8	19.9	38.6
peat:vermiculite	14.6	30.8	53.7	91.7	143.8	4.1	5.4	9.3	17.5	36.8
peat:perlite	15.0	33.8	57.8	97.4	152.4	4.2	6.0	9.8	17.9	37.8
peat:sand:pinebark	14.7	32.8	55.1	100.0	144.8	4.1	6.0	9.5	9.5	39.6
Container										
Hillson (175cc)	14.9	33.4	56.2	97.5	152.6	4.3	6.1	10.1	20.0	40.3a
Fives (65cc)	14.8	31.9	53.4	92.9	141.9	4.0	5.5	9.1	17.4	35.9b

[1] Means separated by lower case letters were significantly different at $p<0.05$. Remaining means were not significantly different.

after the third year, deer had browsed numerous seedlings. Deer repellent was applied to minimize future damage and it was generally effective.

Location of deer browsed seedlings is presented in figure 1. The eastern and southern plantation boundaries, near the edge of the old-field, were bordered by a mature oak-hickory stand of sufficient stocking to provide secure cover for deer. The northern and western plantation boundaries were additional portions of the old-field. Plot maintenance was not extended to the non-plantation portion of the old-field, therefore dense vegetation,including hardwood tree seedlings, had developed by year five.

There were two patterns of deer browse in the plantation. Seedlings were browsed along the plantation perimeter and across the plantation as marked in figure 1. These browsed strips may have been travel corridors for deer moving to the intermittent stream along the northwestern and western old-field boundary and to other feeding areas.

Browse damage was usually restricted to the terminal and always growth of the current year. Rarely did deer feed on lateral branch tips. Normal damage was a resin covered stub, void of buds but with a few needles persisting. Non-browsed secondary branches had buds.

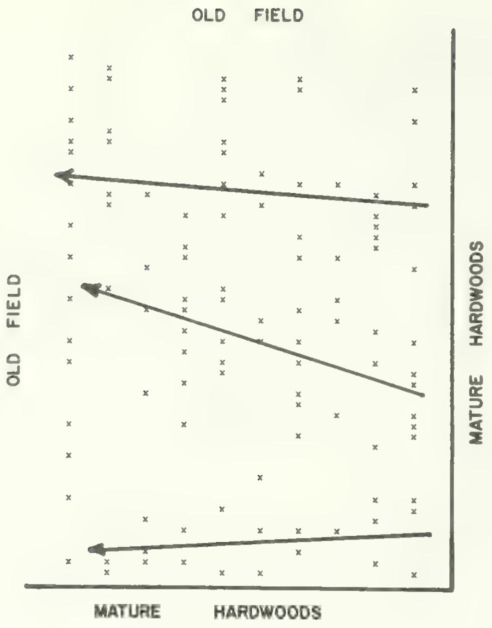

Figure 1.--Browsed white pine seedlings in an old-field at Ames Plantation. Probable travel routes are marked. North is toward the top.

Deer Browse Preference. Table 2 presents the distribution of browsed seedlings by photoperiod treatment during greenhouse culture. Data are expressed as percentages of browsed seedling occurrences. Eighty percent of the seedlings in the study received the 24-hour photoperiod and 20% received natural photoperiod interrupted by 15 minutes of light per hour during the dark phase. Thirty-six percent of the seedlings had been browsed.

Table 2.--Distribution of browsed and non-browsed white pine seedlings that had received supplemental photoperiod during greenhouse culture

	Browsed percent	Non-browsed percent	Total percent
24-hour photoperiod	71	85	80
Natural photoperiod	29	15	20
Total	36	64	100

Deer preferred seedlings that had received natural photoperiod during greenhouse culture ($P<0.004$). Although natural photoperiod seedlings comprised only 20% of the surviving seedlings when browse damage occurred, 29% had been browsed while only 71% of the 24-hour photoperiod seedlings had been browsed. The non-browsed, 24-hour photoperiod seedlings comprised a larger share of the population than was expected.

Sapling Size. Because greenhouse culture treatments had minimal effect on seedling growth at the time of browse occurrence, seedling size was analyzed according to browsed or non-browsed individuals. Height and stem diameter means are presented in table 3. Deer browse caused a significant reduction in sapling height and diameter. ($p<0.01$). Differences between means increased through year five in (fig. 2). The non-browsed saplings were significantly taller than the browsed saplings at year five and every indication is for that trend to continue.

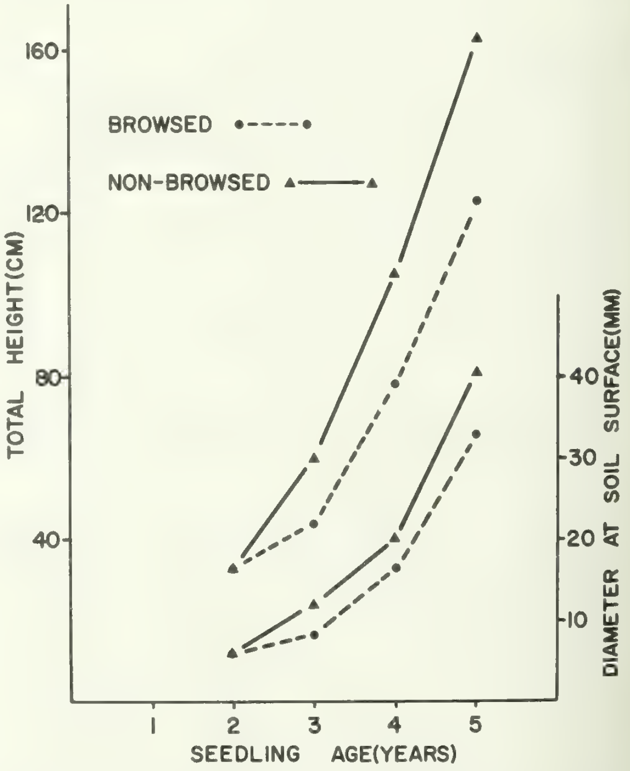

Figure 2.--Height and diameter of white pine seedlings planted on an old-field at Ames Plantation as affected by deer browse.

DISCUSSION

This study fulfilled the original objectives; first year growth exhibited

Table 3.--Total height and diameter at the soil surface for browsed and non-browsed white pine seedlings at Ames Plantation, Tennessee. Browsed damage occurred at year three

Years after planting	Total Height	
	Browsed	Non-Browsed
	cm	cm
2	33.4	32.6
3	44.1	60.2**[1]
4	78.2	105.0**
5	122.9	162.8**
	Stem Diameter at Soil Surface	
	Browsed	Non-Browsed
	mm	mm
	5.8	5.9
	8.5	10.2**
	16.3	20.0**
	33.2	40.4**

[1] Means marked by ** are significantly ifferent at probability <0.01.

ormal form. Greenhouse culture reatments had minimal effect on growth uring the first growing season in the ield; seedlings grown with natural hotoperiod were significantly taller han seedlings grown with 24-hour photoeriod. Time in the shadehouse after eing removed from the greenhouse, could ave ameliorated many size differences. reviously, size and biomass differences ad occurred after greenhouse culture(Hay 981).

The rather severe deer browse problem n this plantation was not anticipated. here had been some animal damage during e first growing season, probably rabbits clipping the young seedlings. However, weeds within the rows soon overtopped the seedlings, providing protection which was maintained during the winter. At the end of the second growing season the seedlings were more apparent within the weed cover and after the third year they were taller than the weeds. It was at this time that browse became a problem. Deer repellent applied during the third and subsequent winters was effective.

Which Seedlings to Browse

Although browse damage was more prevalent on seedlings that had received natural photoperiod in the greenhouse, it was not clear as to why those seedlings were chosen. It is true that they were significantly taller than other seedlings after the first year, but there were no significant effects of any measured variable when browsing became a problem. Perhaps it was the location of these seedlings within the plantation.

Browsed seedling location was not completely random within the plantation. In addition to browse damage along the perimeter, there were two strips across the plantation where browse was concentrated. Considering the juxtaposition of the plantation between resting cover and possible feeding areas, it seemed likely that most browse damage occurred incidently as deer moved along travel corridors. Otherwise browsed seedlings would have been randomly scattered throughout the plantation. Certainly the taller seedlings were most likely to be browsed. There was no attempt to identify taste preferences for deer.

Damage and Recovery Forms

White pine is classic in its monocyclic height growth form. One terminal and associated lateral buds are formed on the main stem in mid-summer containing primordia for tissue growth the following spring (Daniel and others 1979). If these buds are destroyed prior to growth initiation, e.g., by deer browse during the dormant season, adventitious buds are not formed and the stub between the browse damage and the next lower whorl of lateral branches soon dies. Since the tree is without an apically dominant terminal, some of the laterals assume a more terminal position with one or two gaining dominance.

Initially there may be a sizable crook in the central stem as the lateral assumes a terminal position. For the first year it may appear that stem form will never recover, but as the stem gains in diameter it becomes more difficult to detect browse damage. Repeated browse damage accentuates stem deformation and it may preclude development of one apically-dominant, central stem.

By the time the browse-damaged tree matures, it will likely be impossible to detect stem deformation based upon exterior bole characteristics. Nevertheless, the pathway of apical dominance change has been permanently recorded within the stem by the annual rings. Usually major defects will occur in boards that contain deformed annual rings. Compression wood cells dominate and fibers frequently break when the board dries. That portion of the board is unstable and would be discarded in most remanufacturing processes.

Growth Loss

Both seedling height and diameter at the soil surface were significantly reduced by deer browsing. Obviously, that portion of the terminal which was clipped constitutes an immediate height loss, but there were also growth losses because it takes time for a lateral to attain apical dominance. It appeared unlikely that browsed seedlings in this study will soon regain the height of unbrowsed seedlings (fig. 2) and the differences will likely become greater in subsequent years.

Stem diameter was also significantly less for browsed seedlings. Photosynthetic area is reduced by browsing and it is probable that less carbohydrate is manufactured. Foliage loss also weakens the seedlings position with competing vegetation. Fewer needles exposed to full-sunlight further reduces photosynthate production. Diameter growth is secondary to height growth in seasonal timing and in allocation of carbohydrate. If there are fewer carbohydrates available in browsed seedlings, then proportionally fewer of them will be allocated to diameter growth functions. Not until the browsed tree dominates surrounding vegetation and has maximum foliage in full sunlight will carbohydrate production return to maximum. Non-browsed seedlings will attain that status several years before browsed seedlings.

CONCLUSION

Deer browse damage caused stem form deformation and growth loss in five year old white pine seedlings. While there were numerous indications that stem form could recover in the absence of additional browsing, the growth loss was highly significant and appeared unlikely to be recovered.

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EFFECTS OF MECHANICAL SITE PREPARATION INTENSITIES ON WHITE-TAILED DEER FORAGE IN THE GEORGIA PIEDMONT[1]

Cynthia G. Locascio, B. G. Lockaby, Jon P. Caulfield,
M. Boyd Edwards, and M. Keith Causey[2]

Abstract.--Five site preparation treatments were compared on a seasonal basis for their effects on white-tailed deer forage in a young loblolly pine (Pinus taeda) plantation in the Georgia Piedmont. Treatment comparisons indicated low to moderate intensity treatments had positive effects on forage production.[3]

INTRODUCTION

With increasing demand for wood products, many small, nonindustrial landowners in the Southeast generate revenue from timber production. Various methods and intensities of site preparation are available. Due to economic constraints, less intensive, mechanical site preparations are generally the most acceptable to this type of landowner. In addition, these landowners are finding that added revenue can be derived from leasing hunting rights to their land, and the game species often hunted is white-tailed deer. This animal is one of the most economically important wildlife species in the Southeast, generating billions of dollars in revenue annually (Langenau et al. 1984).

When leasing white-tailed deer hunting rights, the lessor should provide a habitat which will produce healthy deer populations. Part of this habitat is good quality (nutrient content and palatability) and quantity deer forage (Harlow 1984). Therefore, it would be advantageous for the landowner to use a site preparation conducive to both timber growth and growth of white-tailed deer forage.

The objective of this study was to determine if there were any differences in forage production with varying intensities of mechanical site preparation.

METHODS

The study area was located on the Hitchiti Experimental Forest, approximately 20 miles north of Macon, Georgia, in the lower Piedmont. Prior to harvest, it had naturally regenerated to a loblolly pine - hardwood stand after abandonment of cotton farming in the 1930's (Miller and Edwards 1985).

Study plots were originally established by Dr. Boyd Edwards (Southeastern Forest Experiment Station, Macon, GA) for a loblolly pine growth and survival study currently in progress. These pines were in their fifth growing season when the forage sampling began in September, 1987. Soils in the area were primarily Typic Hapludults (Edwards 1986).

Experimental Design and Treatments

The experimental design was a randomized complete block with 4 blocks and 5 treatments. Each treatment plot was approximately 2 acres, with measurement plots of 0.1 acre within each treatment plot.

Treatments consisted of:

1. Harvest only (H)

2. Chainsaw and plant (CP) - All residuals 1" and greater were chainsawed and the plots handplanted.

3. Shear with KG blade and chop (SC) - After shearing with a KG blade, plots were chopped with a single pass of a drum chopper.

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[1] Paper presented at Fifth Biennial Southern Silvicultural Research Conference, Memphis, TN, November 1-2, 1988.

[2] Graduate Research Assistant, Associate Professor, and Assistant Professor, School of Forestry; Research Ecologist, Southeastern Forest Expt. Stn., USDA For. Serv., Macon, GA 31020; Professor, Dept. of Zoology and Wildlife Sciences, Auburn University, AL 36849-5418.

[3] We would like to thank the Georgia Forestry Commission for funding this project, and the outheast Forest Experiment Station, Macon, eorgia, for providing field support.

4. Shear, rake, burn, and disk (SRBD) - After shearing with a KG blade and raking into windrows, windrows were burned and the ash and debris scattered over the plots and disked into the soil.

5. Control (C) - The control consisted of a 50 year-old, naturally regenerated, loblolly pine-hardwood stand. This was not a control in the usual sense of the word, but was meant to represent preharvest conditions, and to provide an indication of changes occurring in the post harvest period.

Sampling

Sampling methods were similar to those of other forage assessment studies (Hurst and Warren 1980 1983; Hurst et al. 1980, 1982). Ten 1 m^2 circular sample plots were established on each measurement plot. They were placed at 3m intervals along transects and randomly located 3m to either side of the transects. Forage was clipped from ground level to a height of 1.36m. This height represented the average height to which deer browse, as observed in the study area. Twigs and branches were clipped to a diameter limit of 32mm.

Vegetation was categorized in 4 groups: vines, forbs, grasses, and woody. Examples of vines were Japanese honeysuckle (Lonicera japonica), greenbrier (Smilax spp.), and blackberry (Rubus spp.). The woody category consisted of trees and shrubs, and forbs were any herbaceous plants other than grasses. Grasses are self-explanatory. Vegetation was separated into species in the vine and woody groups. Forbs and grasses were not separated but were labeled simply "forbs" or "grasses." Plants were placed in paper bags, subsamples were dried at 80°C for 72 hours, and all samples were weighed to the nearest 0.1 g.

Sampling was done in September and December, 1987, and March and June, 1988, to represent all 4 seasons. For the entire sampling periods, 760 plots were clipped.

A brief discussion of white-tailed deer forage preferences is pertinent. White-tailed deer eat a variety of plants in all the above groups (Hurst and Warren 1983) and preferences vary from population to population. Therefore, it is difficult to make definitive statements regarding the preferences of a particular deer herd in a specific locale, without doing food habit studies on that particular population (Harlow 1974). However, rumen analysis (Harlow and Hooper 1971) and Aldous browse surveys[4] in the Piedmont have shown the vine and woody categories to be important year-round. These categories accounted for the largest percent volume in the rumen studies for every season except spring, when they were equal to forbs. Grasses comprised a large volume in winter. Vines such as Japanese honeysuckle and greenbrier are especially important since they grow and retain their nutritive value all year (Causey and Sheldon 1974; Blair et al. 1977).

RESULTS AND DISCUSSION

Analysis of variance was used to test for treatment differences, with mean separations being conducted according to the Duncan's Multiple Range Test at the 0.05 level of significance (SAS 1985; Steel and Torrie 1980). Differences occurred for all treatments in each season. Treatments are listed in the tables in order from least to most intensive. Numbers are in terms of dry weight.

ANOVA results for the fall sample period are presented in table 1. In the vine category, the SC showed more production than other treatments. Forbs production was significantly different for the moderate to high intensity site preparations vs. the C and H. Grasses and woody groups showed significant differences, but no trends were evident with site preparation intensity. Numerically the greatest production of grasses was on the SRBD, and woody production was greatest on the CP.

Table 1.—Fall ANOVA results for Sept., 1987, forage dry weights[1]

Treatments	Vines	Forbs	Grasses	Woody
	g/m^2			
C	16.3 bc	3.8 b	19.2 c	18.2 b
H	18.7 bc	7.1 b	47.8 ab	38.9 ab
CP	36.0 b	21.6 a	51.8 ab	58.3 a
SC	64.5 a	22.9 a	37.2 bc	55.3 a
SRBD	10.6 c	28.6 a	58.4 a	31.0 ab

[1] Column means followed by the same letters are not significantly different at the 0.05 level.

The winter ANOVA (table 2) showed significantly greater vine production on the SC vs. the C and SRBD. Numerically, the low to moderate intensity treatments (H, CP, SC) produced the most vines. Forbs, grasses and woody showed significant differences, but no trends occurred with site preparation intensity. Numerically, forbs and grasses were greatest on the most intense treatment (SRBD). The greatest woody production occurred on the CP.

Results of the spring ANOVA are shown in table 3. The SC produced significantly more vines than the SRBD, the latter producing numerically less vine dry weight than other treatments. Forb and grass production was significantly higher on the SRBD. No significant differences occurred in the woody group, although the CP produced the greatest number of woody plants.

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[4] R. Shell 1987, 1988, personal communication.

Table 2.--Winter ANOVA results for Dec., 1987, forage dry weights[1]

Treatments	Vines	Forbs	Grasses	Woody
	g/m²			
C	6.6 b	0.0 b	0.7 c	4.4 b
H	10.4 ab	0.1 ab	4.3 bc	9.2 ab
CP	13.2 ab	0.5 ab	8.5 ab	19.3 a
SC	18.8 a	0.2 ab	3.5 bc	11.4 ab
SRBD	7.3 b	0.6 a	10.2 a	14.2 ab

[1]Column means followed by the same letters are not significantly different at the 0.05 level.

Table 3.--Spring ANOVA results for March, 1988, forage dry weights[1]

Treatments	Vines	Forbs	Grasses	Woody
	g/m²			
C	23.0 ab	0.0 b	0.1 c	13.3 a
H	24.6 ab	1.0 b	4.4 b	11.6 a
CP	22.7 ab	1.3 b	1.5 bc	19.8 a
SC	33.5 a	1.3 b	3.8 bc	14.3 a
SRBD	9.4 b	3.3 a	9.6 a	13.1 a

[1]Column means followed by the same letters are not significantly different at the 0.05 level.

The summer ANOVA (table 4) indicated the fewest statistical differences. Vine production was significantly greater for the SC vs. the other treatments except C. Numerically, the SRBD produced substantially less vines than other treatments. Forb and grass production was greater in all treatments vs. C. No differences occurred in the woody category, although numerically the CP treatment again produced the most woody forage.

Table 4.--Summer ANOVA results for June, 1988, forage dry weights[1]

Treatments	Vines	Forbs	Grasses	Woody
	g/m²			
C	50.1 ab	5.3 b	3.3 b	17.2 a
H	32.6 bc	24.9 a	31.3 a	23.9 a
CP	38.6 bc	18.6 a	24.2 a	50.5 a
SC	69.5 a	28.2 a	22.6 a	22.1 a
SRBD	15.8 c	24.2 a	31.6 a	19.0 a

[1]Column means followed by the same letters are not significantly different at the 0.05 level.

The average number of vine and woody species per treatment was calculated to give some indication of diversity. Diversity is important because nutrient content and digestibility of forage varies with species and season (Short 1975; Blair et al. 1977). These numbers have not been statistically analyzed at this time. The greatest number of vines and woody species were produced on the moderate intensity treatments CP and SC, with 18 and 17 species, respectively. Harvest only and SRBD were next in production with 15 and 14 respectively. Eleven woody and vine species were found on the control.

Total forage biomass for each treatment across all seasons was calculated. Total biomass is potentially biologically significant since quantity as well as quality (nutritional content) of forage is important (Harlow 1984). Results have not been subjected to statistical analysis. Greatest biomass was produced on the SC (409.1 g/m²). Next in production was CP (386.3 g/m²), followed by H (290.9 g/m²), SRBD (287.2 g/m²), and C (182.1 g/m²).

In summary the trends shown by the study were:

1. Forage was increased by harvest and/or site preparation.
2. Forage production was greater on the moderate intensity treatments.
3. Numbers of vine and woody species increased after harvest/site preparation.
4. Numbers of vine and woody species numbers were greatest on the moderate intensity treatments.

Treatment differences for forage quantities are best viewed in the context of pine growth and survival data from the site. Over the past 5 years, statistical analysis has shown the following general results[5]:

Pine Growth (height and diameter):

SRBD = SC = CP > H

Pine Survival:

SRBD = SC = CP > H

The SC and CP treatments which consistently produced more forage biomass in all categories, also produced acceptable timber growth. These treatments could, therefore, provide the small private landowner with the multiple economic benefits of timber and deer forage production.

CONCLUSIONS

Results indicate that low to moderate intensity mechanical site preparations which produce increased quantities of forage, are also effective for pine production. This is good news for the small, nonindustrial forest landowner who wants to manage for timber and white-tailed deer. With increased quantities of forage and proper management, the owner should be able to produce healthy deer populations on this property. This land would be potentially more appealing for hunting lessees, while still providing satisfactory income from timber production.

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SOME EFFECTS OF PERIODIC WINTER FIRE ON PLANT COMMUNITIES ON THE GEORGIA PIEDMONT[1/]

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Abstract.-- Belt transect and planar intercept sampling were used to characterize the vegetation in two management compartments of the Piedmont National Wildlife Refuge that have been prescription burned every fourth or fifth winter since 1964 and one that has remained unburned. These fires drastically reduced plant community stature but did not alter species composition. Expressions of species frequency, density and importance were derived and compared. Results are discussed from a wildlife standpoint.

INTRODUCTION

The Piedmont National Wildlife Refuge (PNWR) covers about 35,000 acres of the lower Piedmont, 25 miles north of Macon, GA. The PNWR was created by executive order in 1939 on severely eroded land that had been farmed for cotton for over 100 years before being abandoned. Management objectives of the PNWR are to: 1) provide suitable habitat for indigenous wildlife species, 2) manage the timber resource on a sustained yield basis, and 3) serve as a demonstration area to show the results of integrating these two objectives. To facilitate accomplishment of these objectives, the refuge was divided into management compartments of roughly 1,000 acres each. The 20 to 40 acre mixed pine-hardwood stands within a compartment are managed on an approximate 80-year rotation with cuttings scheduled every 8 years once a stand reaches pulpwood size. Most compartments have been on a 4-year winter prescribed burning cycle since 1964, although 5 years have occasionally elapsed between burns because of insufficient burning weather during a given winter. Firing techniques have varied but the overriding concern has been to keep fire intensity low.

The study described here was conducted to evaluate the effects of this burning program on the vegetation after 20 years. The impact of burning on the resident fauna is briefly discussed. More detailed discussions can be found elsewhere (e.g. Benford 1968, King 1982, Speake et al 1975, and USDI Fish and Wildlife Service 1985). Changes in vegetative structure were visually obvious, but PNWR personnel wanted to quantify these changes. They wanted answers to the following questions: What are the effects upon commonly found shrubs and trees? Are any plant species being eradicated? Is pine regeneration adequate? Is the number of mast-producing trees decreasing?

METHODS

To answer these questions, we conducted a vegetative survey in two burned compartments and one adjacent unburned compartment during the summer of 1983. We chose the fourth growing season after burning because we were primarily interested in the long-term effects of the 4-year winter burning cycle. Conducting the study during an earlier postfire successional stage would have yielded a substantially higher number and amount of herbs. The response of herbaceous vegetation to fire in the lower Piedmont has previously been documented (Cushwa and others,1966; Cushwa and others, 1970; King 1982).

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Table 1.--List of minor species (species occurring on less than 5% of all transects within a survey) and total number of transects within which a minor species was encountered. Excludes those species that were minor or absent in one survey but common in the other.

Species	Total number of transects species found in Unburned Compartment	 Burned Compartments
Acer leucoderme	1	1
Albizia julibrissin	3	1
Amelanchier arborea	2	0
Asimina parviflora	4	2
Campsis radicans	1	2
Carpinus caroliniana	2	0
Castanea pumila	0	2
Euonymus americanus	1	2
Fagus grandifolia	1	0
Ilex decidua	4	0
Ilex opaca	1	2
Juniperus virginiana	1	2
Magnolia acuminata	2	1
Prunus spp.	1	0
Rhododendron spp.	1	1
Rhus glabra	0	1
Sassafras albidum	0	1
Styrax grandifolia	1	0
Ulmus americana	1	0
Vaccinium arboreum	8	5
Viburnum nudum	1	1
Viburnum rufidulum	7	6
Vitus aestivalis	0	2
Unknown	3	3

Table 2.--Basal area by species, aspect, and burning treatment for woody plants greater than 4.5 ft. tall.

Species Group	NE		SE		SW		NW	
	B	U	B	U	B	U	B	U
Acer barbatum	2.2	0.2	0.0	0.2	2.4	0.8	4.0	1.1
Acer rubrum	0.3	1.1	0.7	1.7	2.6	1.5	0.7	1.2
Callicarpa americana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carya spp.	0.6	3.1	0.1	11.7	1.5	1.8	2.9	1.1
Cercis canadensis	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0
Cornus florida	6.5	4.4	6.2	6.5	1.7	3.3	12.0	4.3
Crataegus spp.	1.0	0.7	0.4	0.2	0.0	0.4	0.2	0.9
Diospyros virginiana	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1
Fraxinus spp.	1.1	2.5	0.0	0.8	2.3	1.5	1.3	3.1
Liquidambar styraciflua	2.7	7.6	7.8	6.5	10.4	14.7	3.4	10.9
Liriodendron tulipifera	0.0	0.9	1.5	2.1	1.1	8.1	2.9	1.8
Morus rubra	0.0	0.0	0.0	0.3	0.0	0.6	0.3	0.0
Nyssa sylvatica	0.1	1.4	1.1	0.9	1.8	0.5	0.7	1.5
Ostrya virginiana	0.0	0.0	0.0	0.1	0.0	0.0	0.1	2.0
Pinus echinata	7.0	13.2	7.8	1.1	8.3	25.6	4.8	6.1
Pinus taeda	70.1	56.7	72.1	83.0	75.2	55.0	72.2	65.5
Prunus serotina	0.6	0.3	0.5	0.1	0.1	0.3	0.2	0.4
Quercus spp. (red oaks)	10.3	1.3	8.0	11.6	1.7	11.2	2.0	5.2
Quercus spp. (white oaks)	4.8	4.9	4.1	12.2	3.1	14.2	4.6	11.2
Rhus copallina	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Ulmus alata	3.0	2.4	7.4	0.4	0.9	1.4	0.8	1.5
Total	110.3	101.0	118.0	139.6	113.3	141.1	113.0	117.9

Two separate surveys were conducted: one for woody vegetation taller than breast height (4.5 feet above ground) and one for ground cover and vegetation less than breast height. One hundred sixty-six belt transects, each 8 feet wide by 100 feet long, were established to assess the taller vegetation. Plants less than 4.5 feet high were surveyed by the planar intercept method along the first 50 feet of each belt transect midline.

Pine and hardwood basal areas were estimated with a 10 factor prism at the 50-foot mark of each transect. Transects were located along contours at elevations between 425 and 500 feet in order to maintain position within the mid to upper third of a slope. At least 20 transects were laid out on each of four aspects: northeast, southeast, southwest, and northwest. All transects were on Davidson soils except for six that occurred on Gwinnett soils. Recent cutting had not taken place in any of the surveyed stands. The overstory was all-aged with the oldest pines over 80 years in age.

The belt transect data included all stems greater than 4.5 feet tall that originated below groundline within a transect. Each was tallied as an individual plant. On line transects, plants of all sizes were tallied whenever a stem intersected an imaginary vertical plane running from groundline to a height of 4.5 feet. If a plant had a crooked stem and intersected this plane more than once, it was tallied more than once. Each 50 foot transect was divided into 1-foot segments and the species with the largest number of interceptions within each segment recorded. When more than one stem of a species was tallied within a segment, the total number of stems of that species within the segment was also recorded. Since this number included plants taller than 4.5 feet that intersected the plane below 4.5 feet, as well as plants with crooked stems that were counted more than once, the total number of plants less than 4.5 feet tall could not be determined. If the majority of a 1-foot segment did not contain vegetation, that segment was classed as void for the purpose of determining dominance.

DATA

We found the area to be floristically diverse. Close to 100 individual species were identified and placed in 58 species groups. In some cases, species within a genus were not individually recorded. The oaks were divided into two subgenera -- Erythrobalanus (red oaks) and Leucobalanus (white oaks). Species encountered on less than 5 percent (9) of the transects within a survey were classed as minor and dropped from statistical analyses. A combined list of the minor species and species groups encountered in both surveys can be found in table 1. The total number of transects by treatment that a minor species was found in is also shown in table 1. Species or species groups common in one survey but minor or absent in the other, such as Georgia hackberry (Celtis tenuifolia Nutt.), were omitted from table 1.

For each belt transect, basal area (BA), stem density (average number of stems/acre), and stocking (the number of transects in which a species was encountered) were calculated by species. An analysis of variance (ANOVA) was performed by species to determine the effects that burning regime and transect aspect had on basal area, stem density, and stocking. If a factor was found significant (p=0.05), Tukeys honest significant difference test (HSD) was performed to separate individual means.

For each line transect, the number of intersections and the number of 1-foot segments dominated by each species were summarized. Relative frequency (frequency of an individual species divided by sum of the frequencies of all species) and dominance (number of one-foot segments dominated by a species) were calculated for each species by transect. ANOVA was used to determine the effects of burning and aspect on the count and dominance (Importance Value) of all planar transect vegetation.

RESULTS

Plants Greater Than 4.5 ft Tall

Of the 39 species groups identified on the belt transects, 18 were classed as minor. Fourteen minor species occurred in the unburned compartment and 9 in the burned compartments.

Basal area averaged 120 sq.ft. per acre and did not differ by burning regime or aspect (table 2). Loblolly pine (Pinus taeda L.) dominated BA on all aspects in all compartments averaging 72 sq.ft. on the burned areas and 65 sq.ft. on the unburned compartments. Shortleaf pine (Pinus echinata Mill.) was a distant second with average basal areas of 7 and 12 sq.ft. on the burned and unburned compartments, respectively. Hardwoods making up a major portion of the remaining BA included sweetgum (Liquidambar styraciflua L.), the white oak and red oak groups (Quercus spp. L.), flowering dogwood (Cornus florida L.) and hickory (Carya spp. Nutt.).

Dogwood was the most numerous species in all three compartments, comprising 23 percent of all woody plants greater than 4.5 feet tall (table 3). Sweetgum was the second most abundant species, comprising an additional 16 percent of all stems. Loblolly pine was third with 14 percent. All other species averaged less than 100 stems per acre.

Table 3.--Mean number of plants per acre by species, aspect, and burning treatment for woody plants greater than 4.5 ft. tall.

Species Group	Aspect							
	NE		SE		SW		NW	
	B	U	B	U	B	U	B	U
Acer barbatum	52	26	65	16	191	14	25	30
Acer rubrum	80	46	87	125	93	125	33	131
Callicarpa americana	5	9	0	0	27	14	3	0
Carya spp.	39	102	30	68	33	109	74	106
Cercis canadensis	0	13	16	16	3	5	19	14
Cornus florida	340	305	327	319	280	449	177	210
Crataegus spp.	52	111	8	54	5	54	19	109
Diospyros virginiana	16	37	19	22	16	11	11	25
Fraxinus spp.	29	26	3	25	11	38	52	44
Liquidambar styraciflua	153	211	188	180	335	289	133	177
Liriodendron tulipifera	0	13	16	11	8	27	22	22
Morus rubra	3	9	0	25	0	16	3	3
Nyssa sylvatica	16	15	5	27	30	14	44	44
Ostrya virginiana	0	4	0	14	0	3	16	87
Pinus echinata	21	15	30	19	41	54	22	25
Pinus taeda	91	218	131	348	125	191	117	267
Prunus serotina	18	15	16	11	8	25	8	22
Quercus spp. (red oaks)	52	26	30	27	25	41	65	30
Quercus spp. (white oaks)	54	46	38	52	30	46	44	52
Rhus copallina	18	15	0	5	49	38	0	5
Ulmus alata	78	91	52	35	25	207	65	103
Total	1115	1355	1062	1399	1334	1770	950	1503

Burning significantly reduced the number of stems per acre (table 3). The average number of stems per acre on the unburned area was 26 percent higher than the 1,115 in burned compartments. Examination of the diameter distributions of the burned and unburned areas indicated that this increase occurred in the 0.75, 1.25, and 1.75 inch classes (figure 1). Many of the rapidly growing postfire sprouts surpass 4.5 feet in height within the four growing seasons between fires accounting for the greater number of stems in the smallest diameter class (0.25 inch) in the burned compartments. The next fire then kills many of these sprouts resulting in the dramatic drop in the number of stems that reach the next larger size class on the burned areas. However, continued attrition in the smaller diameter classes in the unburned compartment resulted in roughly equal numbers of stems by the time the trees of many of the species groups reached 2 to 3 inches in d.b.h. Only one species, Florida maple (Acer barbatum Michx.), had significantly more stems in the burned compartments. Hickory, hawthorne (Crataegus spp. L.), red mulberry (Morus ruba L.), loblolly pine, and winged elm (Ulmus alata Michx.) all had significantly fewer stems in the burned areas. Hawthorne had approximately four times as many stems in the unburned compartment. There are actually more loblolly pine stems larger than 3.0 inch d.b.h. on the burned areas, but this fact is overshadowed by the preponderance of small stems in the unburned compartment (figure 2).

The ANOVA indicated that aspect significantly affected number of stems (p=0.0399), but Tukey's HSD test indicated that none of the four means differed. The general shapes of the diameter distribution were plotted for all four aspects and found to be similar - the reverse J of an all-age stand (e.g. figure 3). (the slight increase at 5 inches d.b.h. is due to a change in class interval from one-half to one inch). For several species, the mean number of plants per acre was found to vary significantly among aspects based on Tukey's HSD test. These species are American beautyberry (Callicarpa americana L.), dogwood, eastern hophornbeam (Ostrya virginiana Mill.), shortleaf pine, shining sumac (Rhus copallina L.), and winged elm.

Three species, Florida maple, hophornbeam, and winged elm, showed a significant interaction between burning regime and aspect (table 3). Fourteen times as many Florida maple stems less than 0.5 inch d.b.h. were tallied on the burned transects as on the unburned transects. Except for this smallest d.b.h. class, however, there was little difference in the number of Florida maples between burned and unburned compartments. Virtually all hophornbeam occurred on northwest aspects in the unburned compartment except for a few stems in the 0.25 inch diameter class that occurred on burned northwest aspects. Winged elm was common in all eight treatment/aspect combinations but a large majority occurred on unburned southwest aspects.

Three species occurred on more than 12 percent of all eight burn/aspect combinations. Dogwood had the highest stocking, ranging from 23 to 37 percent. Loblolly pine (16 to 31 percent) was next, followed by sweetgum (13 to 34 percent). Hickory was found on more than 12 percent of all

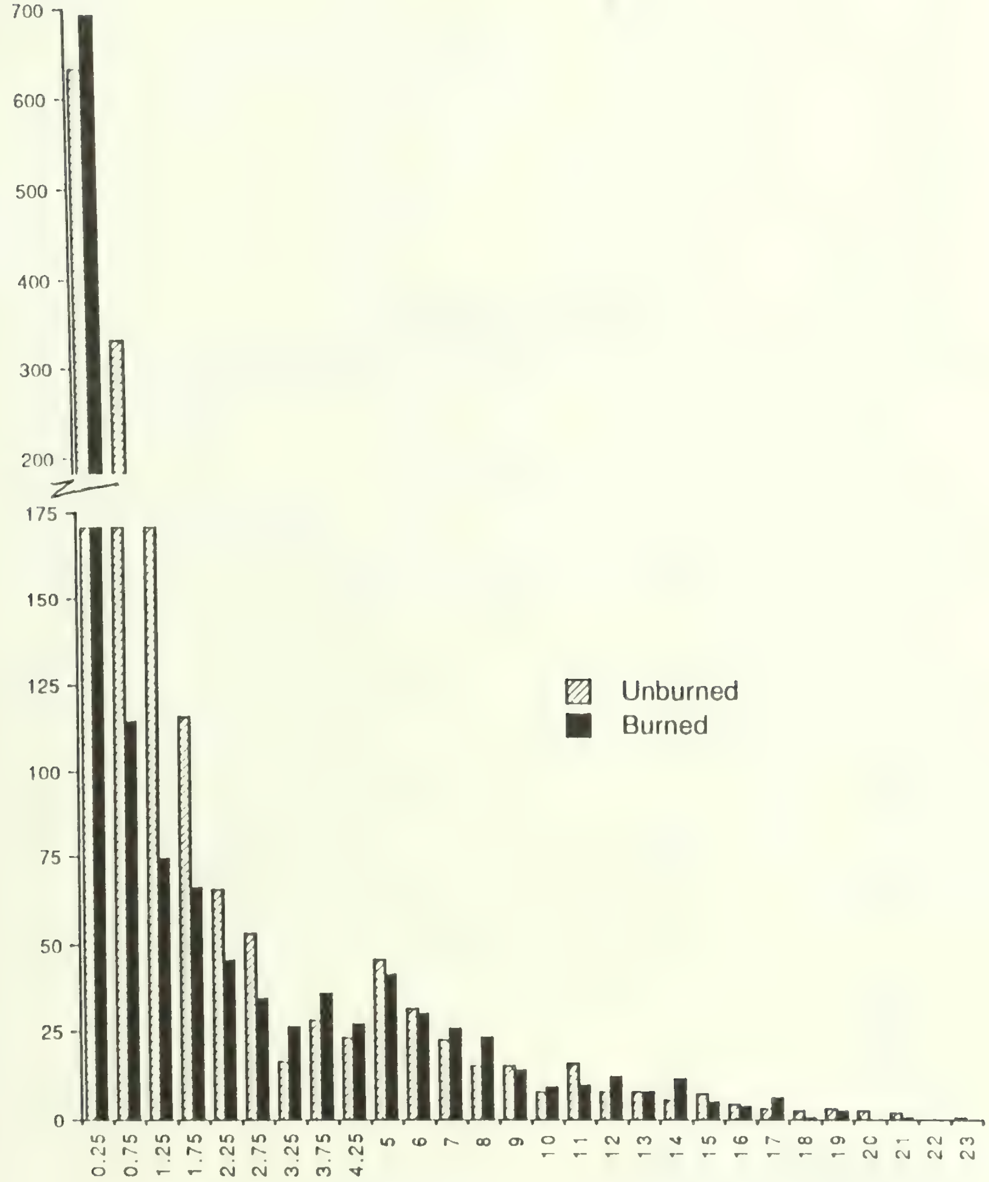

Figure 1.-- D.B.H. distributions of burned and unburned compartments.

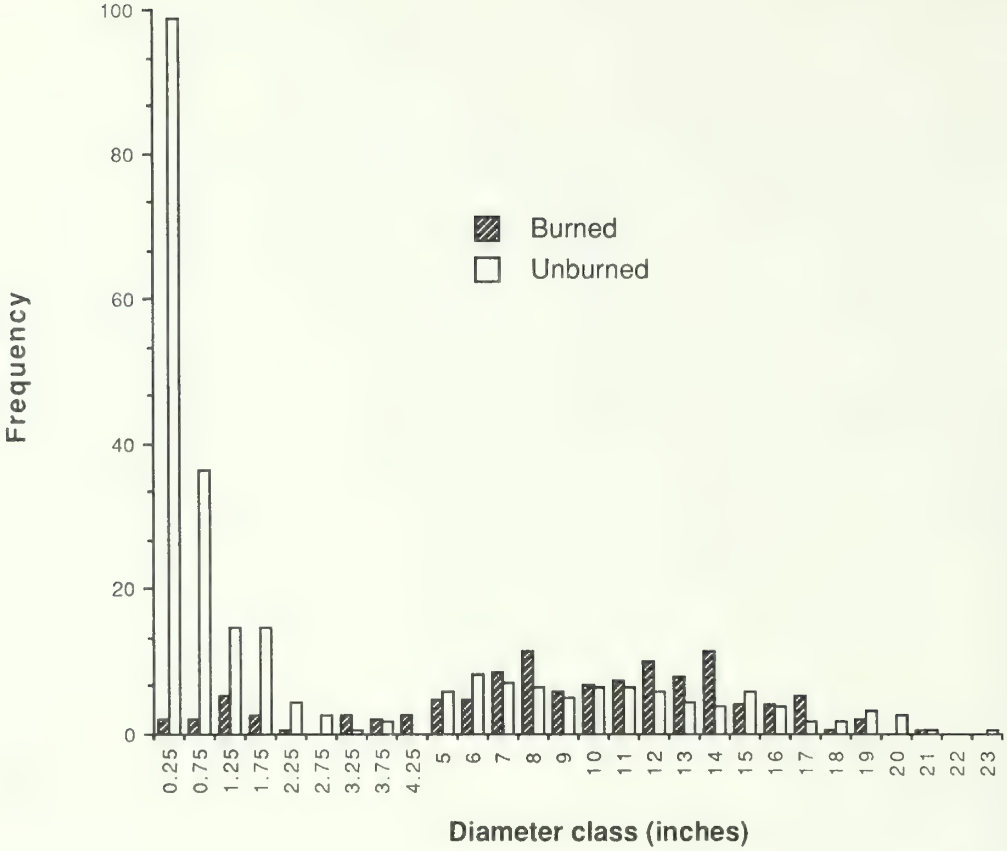

Figure 2.--Diameter distribution of loblolly pine by treatment.

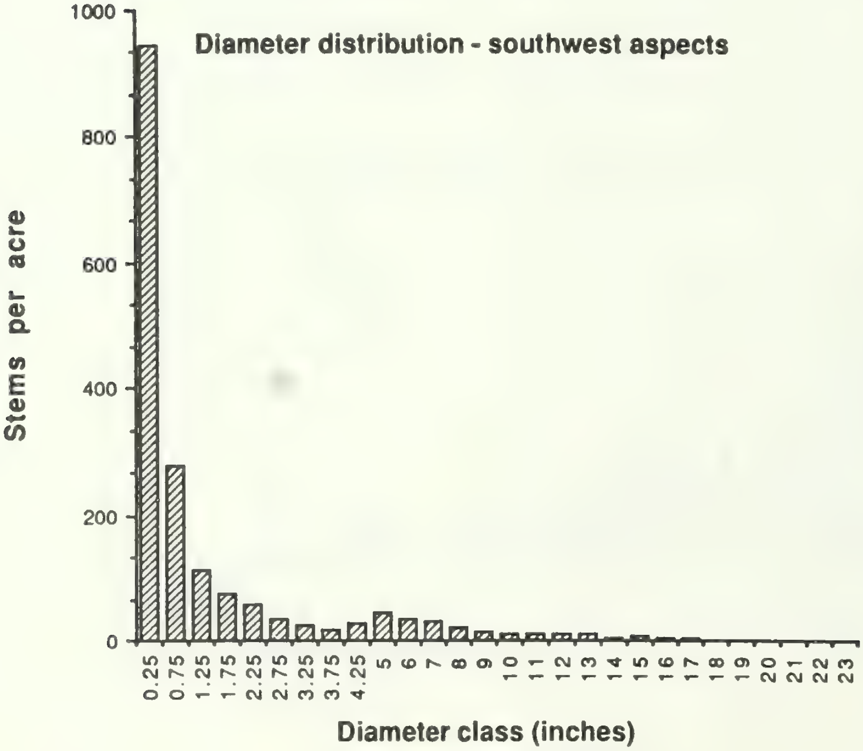

Figure 3.--Diameter distribution of all species greater than 4.5 feet tall on southwest aspects.

unburned transects but reached this level on only the northwest aspect in the burned compartments. Florida maple was found on 17 percent of the southwest burned plots. Red maple (Acer rubrum L.), hawthorne, hophornbeam, and winged elm occurred on more than 12 percent of the transects on one, two, or three aspects in the unburned compartment.

Plants Less Than 4.5 Feet Tall

Twenty-one of the 55 species groups encountered on the planar intercepts were minor and thus dropped from further analyses.

Burning significantly increased the occurrence of herbaceous plants although this species group was also the most common one on the unburned transects. This species group occurred in 50 percent of the 1-foot segments in each burned transect and in 34 percent of the segments in each unburned transect. Muscadine (Vitis rotundifolia Michx.) was the most common individual species on the burned compartments, occurring on 30 percent of the transect segments. Even though this species was also the third most common on the unburned transects (24 percent), the difference was still statistically significant. Dogwood was third on the burned areas being found on 22 percent of the segments in each transect, and second in the unburned compartments (25 percent).

Less frequently encountered species with significantly more intersections (p=0.05) on transects in the burned compartments were Florida maple (8 percent vs 2 percent), Georgia hackberry (four times as many interceptions on transects in the burned areas), Carolina jessamine (Gelsemium sempervirens L.) (virtually all on burned northwest aspects), Japanese honeysuckle (Lonicera japonica Thunb.) (the vast majority on burned northwest aspects), black cherry (Prunus serotina Ehrh.) (three times more prevalent on the burned areas), the red oak group, and greenbriar (Smilax spp. L.) (nearly twice as many on the burned areas). Although the difference was not statistically significant, the occurrence of white oaks averaged nearly 50 percent higher on the burned areas. Species with a statistically significant preference for unburned areas were hickory, loblolly pine, and the void category. The mean number of interceptions per transect by broad vegetation class are presented in table 4.

Mean number of planar transect interceptions also varied by aspect. Species with significant differences between aspects were red maple, Alabama supplejack (Berchemia scandens E.J.Hill), Georgia hackberry (4 to 7 times as many on northwest aspects), hophornbeam (5 to 8 times as many on northwest aspects), and muscadine (about half as many on northwest aspects). A significant interaction between burning regime and aspect was shown for Carolina jessamine and Japanese honeysuckle.

Table 4.--Mean number of interceptions per transect by vegetation class for vegetation less than 4.5 ft tall.

Type	Burned	Unburned
Woody vegetation	40	37
Vines	25	18
Herbaceous	24	17
Void	05	10

Relative frequency is the frequency of an individual species divided by the total frequency of all species. Species with a higher relative frequency in the burned compartments on all four aspects were Florida maple, red maple, Georgia hackberry, herbs, black cherry, blackberry and dewberry (Rubus spp. L.), and viburnum (Viburnum spp. L.). Those species with a higher relative frequency on all aspects of the unburned compartment were hickory, hophornbeam, and "void".

Dominance, the number of 1-foot segments dominated by a species on a transect, varied by treatment and aspect. Muscadine, dogwood, and herbs (in descending order) had the highest values irrespective of treatment. Florida maple, Alabama supplejack (this was the only species that did not occur on all four aspects), hackberry, Japanese honeysuckle, and viburnum all had higher dominance values on all aspects (where they occurred) in the burned areas. The opposite was true of hickory, hophornbeam, loblolly pine, and "void".

Importance values (the sum of the relative frequency and relative dominance) by species, treatment, and aspect are given in table 5. Highest importance values in the burned compartments were shared by herbs and muscadine on all aspects except northwest where dogwood, Japanese honeysuckle, and "void" were all a poor second to herbs. The most important species groups on the unburned compartment were herbs, "void," and muscadine, except on the two westerly aspects where dogwood replaced muscadine.

DISCUSSION

Aspect affected the distribution, number, and size of many of the species examined in this study (tables 2,3 and 5). However, the purpose of this study was to look at fire-induced vegetative changes, so the affects of aspect will not be discussed further. Burning decreased average stem diameter because single large stems were topkilled and replaced by many small sprouts. Thus periodic burning ensures a continuous abundant supply of succulent browse at a level readily accessible to deer and other browsers. This is readily apparent in Florida

Table 5.--Importance value indices of plants less than 4.5 feet tall be species group, aspect and burning treatment.

	NE		SE		SW		NW	
	B	U	B	U	B	U	B	U
Acer barbatum	34.5	7.9	27.0	6.0	29.1	8.9	30.7	18.6
Acer rubrum	41.2	28.1	53.4	52.2	52.4	41.1	27.9	26.1
Berchemia scandens	*	*	7.5	5.4	2.0	*	4.5	*
Callicarpa americana	1.0	1.8	5.8	3.3	5.9	7.0	2.1	*
Carya spp.	12.9	25.0	13.7	18.5	9.9	17.9	10.4	13.6
Celtis tenuifolia	6.1	2.5	3.2	2.1	4.2	3.2	19.0	5.5
Cercis canadensis	2.1	2.8	5.5	8.7	9.0	2.3	15.7	2.6
Cornus florida	66.3	61.4	70.7	57.2	46.2	73.7	52.4	66.0
Crataegus spp.	17.3	17.4	19.2	13.4	29.1	9.6	1.0	17.7
Diospyros virginiana	6.4	7.4	10.0	4.6	7.8	4.4	5.6	2.3
Fraxinus spp.	4.1	6.2	2.2	*	2.1	6.4	5.5	5.6
Gelsemium sempervirens	2.0	*	*	4.0	6.1	*	30.5	*
Herbaceous	94.1	84.6	99.5	93.8	94.0	91.5	103.9	102.3
Liquidambar styraciflua	23.7	26.1	29.3	12.4	39.3	33.7	26.7	32.1
Liriodendron tulipifera	1.0	7.5	7.0	*	7.2	2.2	3.4	2.6
Lonicera japonica	8.3	*	2.1	4.1	8.0	*	55.1	2.6
Nyssa sylvatica	5.5	8.1	6.2	2.2	5.1	4.1	6.3	4.4
Ostrya virginiana	1.0	1.0	*	4.6	1.1	3.5	9.1	25.9
Parthenocissus quinquefolia	6.8	5.2	2.1	*	9.5	8.2	*	5.5
Pinus taeda	10.8	37.4	8.4	31.0	10.7	27.9	27.0	22.5
Prunus serotina	18.4	6.6	13.8	10.1	18.4	4.1	14.1	7.3
Quercus spp. (red oaks)	29.0	30.5	26.4	8.7	25.2	20.5	32.0	25.4
Quercus spp. (white oaks)	14.7	10.6	9.9	5.3	7.9	8.0	10.5	12.2
Rhus copallina	2.2	5.7	3.0	1.1	*	5.3	2.1	3.2
Rosa spp.	4.5	1.7	2.0	1.0	3.2	3.0	*	2.2
Rubus spp.	8.3	5.1	10.1	5.7	10.4	1.0	5.1	4.3
Smilax spp.	48.3	41.0	57.5	41.6	51.0	38.0	40.5	42.7
Ulmus alata	16.9	8.5	11.1	2.1	10.7	20.2	15.9	14.7
Vaccinium spp.	15.0	14.0	16.7	4.9	9.5	11.0	21.1	15.2
Viburnum spp.	2.9	0.8	2.0	*	3.3	3.3	1.0	*
Vines	*	4.7	3.0	*	*	2.1	2.1	*
Vitis rotundifolia	87.3	75.6	110.6	92.0	84.3	69.3	39.3	61.0
Void	62.1	74.2	25.9	93.6	44.0	77.9	59.9	91.4

maple, sweetgum, and redbud (*Cercis canadensis* L.). Substantially more vegetation was encountered on the line transects in the burned compartments while the opposite was true for the belt transects.

All common species were found in both burned and unburned compartments, but burning appeared to discriminate against some species. The hickories seem to be less tolerant of fire than other species. Although they were not eradicated by fire, their numbers were reduced in the small diameter classes on the burned areas. This reduction can be expected to have an adverse effect on nut production over time. Other midstory species adversely impacted by low-intensity winter fires at 4- to 5-year intervals include redbud, hawthorne, yellow-poplar (*Liriodendron tulipifera* L.), red mulberry, hophornbeam, and sumac. Fire has significantly reduced the number of loblolly pine seedlings, but sufficient stems were present to ensure this species would continue to dominate the overstory.

Each of the 58 species groups encountered in this study was put into one of three wildlife value categories: primary, secondary or none. Only one species of either primary or secondary value showed a clear response to burning in the belt transect survey (those plants over 4.5 feet tall). This was hickory which was unfavorably impacted. The situation is entirely different in the planar intercept survey. Again the only species of secondary concern to show a clear negative response to a 4-year winter prescribed burning cycle was hickory. However, nine species of primary concern showed a positive response to this prescribed fire regime. They were Georgia hackberry, black cherry, Carolina jessamine, herbs, Japanese honeysuckle, both the red and white oak groups, blackberry, greenbriar, and muscadine.

The increased abundance of both food and low-level cover resulting from periodic fire attracts a wide range of game and nongame wildlife species such as quail and turkey, and mice and shrews. Unpublished work by David Jennings shows that Cooper's hawk and the more common redtail hawk both feed primarily on the burn areas, undoubtedly because of the dramatically increased small mammal populations. Fox squirrels also favor periodically burned compartments, as do numerous song birds including the rather uncommon Bachman's sparrow.

Perhaps the most important consequence of burning on the PNWR is the beneficial relationship between fire and the red-cockaded woodpecker, a rare and endangered species whose management is dictated by law. A sparse to non-existent midstory must be maintained to favor this bird. Ongoing research on the PNWR by Dr. Lennartz shows that midstory basal area of active colonies averages 33 ft^2/ac. As the basal area approaches 55 ft^2/ac, sites are abandoned. Our study did not differentiate between mid- and over-story basal area, but if one assumes pines dominated the overstory and hardwoods the midstory (as can be inferred from Table 2), our data shows an average midstory BA of 35 ft^2/ac on the burned areas and 48ft^2/ac in the unburned compartment.

SUMMARY AND CONCLUSIONS

Approximately half of the 58 species groups encountered occurred on less than 5 percent of the transects in a survey. The 4-year winter burning cycle has retarded midstory formation, holding succession at an earlier seral stage. All common species were found in both the burned and unburned compartments. Hickory, redbud, red mulberry, eastern hophornbeam and sumac were found to be somewhat intolerant of fire. Loblolly pine dominated the overstory in all three study compartments and sufficient stems are in the understory to ensure dominance will continue in the foreseeable future. Dogwood (a tree of both aesthetic and wildlife value) and sweetgum (generally considered the major problem species on Piedmont sites being managed for pine) dominate the midstory of both burned and unburned compartments. Principal understory trees were dogwood and red maple, regardless of treatment. Florida maple was favored by burning, while understory hickories were not. Ground cover was comprised primarily of herbs, muscadine, and greenbriar across all eight treatment/aspect combinations. A much larger percentage of the forest floor was devoid of vegetation in the unburned compartment.

The total number of understory stems was increased by burning, thereby maintaining abundant wildlife browse and cover. None of the 14 species groups judged to be of primary wildlife value were adversely affected by burning. To the contrary, increased understory frequencies were noted for several "primary" species in the burned compartments. This study quantified the visual impression that 20 years of winter burning on the PNWR has drastically modified vegetative stature but has not altered composition, and that these changes have had a beneficial effect on wildlife.

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IMPACTS OF LOBLOLLY PINE REGENERATION ON SELECTED WILDLIFE HABITAT COMPONENTS[1]

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Abstract.--The impacts of loblolly pine regeneration on wildlife habitat components were examined in the Piedmont of South Carolina. Pines were regenerated by either the seed-tree method or planting, both following chop-and-burn site preparation. Linear and quadratic models were fit to the logarithm of forage weight. In natural stands, logarithm of most forage components (woody, herbaceous, vine, and total dry weights) exhibited a steady decline with age. Logarithm of grass forage in natural stands and all forage components in plantations exhibited a curvilinear relationship to stand age. Timing of the site preparation burn, seedfall patterns, and pine density strongly influenced responses of forage to stand age. Implications for management of white-taled deer habitat are discussed.

INTRODUCTION

Loblolly pine (Pinus taeda) is a major tree species in the South, naturally occupying one-fourth of the forest land area (Langdon 1981). Additional forest land, mainly that of forest industry, commonly is converted to loblolly pine. A wide variety of procedures are available to prepare a site for loblolly regeneration. Several studies have examined the impacts of various techniques on soil properties, vegetation development, and growth and survival of loblolly (Edwards 1982; Lantagne and Burger 1982; DeWit and Terry 1982).

Harlow and Van Lear (1981, 1987) reviewed the literature covering impacts of silvicultural practices on wildlife indigenous to the southern pine ecosystem. Many studies have addressed effects of management techniques (e.g., fertilization, prescribed burning, etc.) or impacts of site preparation on vegetation development (Stransky and Halls 1980; Felix et al. 1983). Most studies cover only the initial 5 to 8 years of loblolly establishment. Our objective was to document changes in forage development over time in planted and naturally regenerated loblolly pine stands.

STUDY AREAS

Study areas were located in the Piedmont Plateau Privince of western South Carolina in Abbeville, Edgefield, Greenwood, McCormick and Saluda Counties. Average annual temperature in the area was 16.7 C and yearly precipitation averages 150 cm (NOAA 1984).

Ten stands, regenerated naturally to loblolly pine using the seed-tree regeneration method, were located on the Sumter National Forest. These stands had been cut to 15-20 seed trees per hectare, followed by site preparation which consisted of chopping and summer burning. Regenerated stands ranged from 3 to 22 years old and stand size averaged 16 ha (range 4 to 25 ha). Site index averaged 25 m at base age 50 years. Previous stand types on the study areas ranged from 27 to 61-year-old loblolly and shortleaf (P. echinata) pine. Aspect varied from 160° to 340° and slopes averaged about 4% (range 3.0% to 5.5%).

Fifteen plantations were located on lands owned by International Paper Company and were selected on the basis of proximity to natural stands, site preparation, and stand history. Stand ages ranged from 2 to 18 growing seasons. These sites were planted with 1-0 loblolly pine seedlings on a 2.1 X 3.0-m spacing yielding 1,537 trees per ha. Site index (age 50) in plantations was 25 m. Aspect varied from 84° to 288° and slope averaged 5% (range 3.5% to 9%). Site preparation consisted of shearing and chopping residual stems followed by summer broadcast burning. Previous stand types on the study sites were generally old-field loblolly pine.

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MATERIALS AND METHODS

In natural stands, seedlings were distributed in clumps. In order to sample areas of dense and sparse aggregations of pines, transect lines were randomly located perpendicular to the contour across the study areas. A 20 X 20-m grid was overlain on a map of each study area. Grid points were numbered and a random number table was used to select five lines in natural stands. In each of these stands, a starting point along each line was also randomly chosen. Five sequential sampling points, 20 m apart, were selected on each transect line. In plantations, only the first grid point was chosen with the random number table and 25 sample points were located sequentially in a grid arrangement.

Procedures for habitat analysis were modified from James and Shugart (1970), Dueser and Shugart (1978), and Barbour et al. (1980). A circle 3.56-m radius (0.004 ha or 0.01 ac), and a rectangular plot 0.25 X 2-m (0.5 m^2) were located on each of the 25 stations on each study area. Circles were centered on the station point while the rectangular plot was offset 2 m and parallel to the line of travel. Density of pines was measured by counting the number of living pines in each 0.004 ha plot. Two measures of tree spatial pattern were computed using the mean and variance of trees per 0.004 ha plot. First, the "coefficient of dispersion" (D) (Greig-Smith 1964:65) was computed as D = (variance/mean desnity). A value of D = 1 indicates a random distribution, values less than 1 indicate a univorm pattern, while values greater than 1 indicate a clumped arrangement (Greig-Smith 1964:66). The second measure of spatial pattern, Lloyd's "index of crowding" (m*) (Pielou 1977:131), was computed as a measure of the mean number of neighbors around individual stems in each sample plot. Numerically, crowding is the sum of mean density and the index of clumping. Crowding is experienced by each individual in the population and depends on density (Pielou 1977:131).

Above-ground biomass of forage was determined by clipping current growth of all plants rooted in the rectangular polot up to a height of 1.5 m. Clipped material was separated into 4 categories: woody, herbaceous, vine, and grass, and dried in a forced-air oven at 60 C for a minimum of 72 hours (Hurst and Warren 1980).

Vegetation data were averaged for each stand, examined for normality and transformed using logarithmic transformation. Relationships between forage components and stand ages were examined by fitting a linear model to the data by the method of least squares. Curves were tested for lack-of-fit (Draper and Smith 1981:33). Statistical significance was set at the 5% probability level unless otherwise specified in the text.

RESULTS

Distribution of trees was considerably different between natural stands and plantations (fig. 1). In natural stands, the range of desnity within sample plots was wide with 13 percent of the 0.004 ha plots having 0 or 1 tree and 22 percent of the plots having 20 trees or more. A few plots had as many as 70-80 seedlings. The index of clumping was high (21.9) and indicated a significant departure from a random distribution (t = 243.4, d.f. = 247, P   0.001). The index of crowding was 34.2. Taken together, values of clumping and crowding indicate that these natural stands consisted of dense, randomly distributed clumps of trees. Askew (1983) found similar results for natural loblolly stands 4 to 29 years old in the South Carolina Coastal Plain.

In plantations, density was less variable with only 5 percent of the plots having 1 tree or less. Also, no plots had more than 20 trees. The index of clumping was low (1.9) indicating a significant departure from a random distribution (t = 25.3, d.f. = 373, p   0.001). The index of crowding was 6.9. Plantations begin as an ordered arrangement of seedlings, but random deaths in the stand contribute to the formation of occasional clumps of pines. These clumps are less dense (i.e., less crowded) than in natural stands.

Weight of most forage components declined with stand age. In natural stands, the decline was generally loglinear (fig. 2). Grass forage weight was the exception, being best described by a quadratic function (table 1). Maximum production of grass forage occurred at 6.4 years of age (table 2). The lack-of-fit test indicated that all models, except the linear model for herbaceous forage on natural stands, adequately described the relationship (table 3). Visual examination of the data for herbaceous forage does not suggest that a higher order model would provide a better fit of the data. More observations at each concomitant position perhaps would have clarified this relationship. For the moment, an r^2 value of 0.92 would indicate some usefulness to this model.

In plantations, weight of forage variables first increased in value then declined after 6-8 years (table 2). The quadratic model best described the trend of forage weight and age in plantations (table 1). Total forage development in plantations peaked at age 6 then declined (fig. 2). There was no evidence that any models were inadequate (table 3).

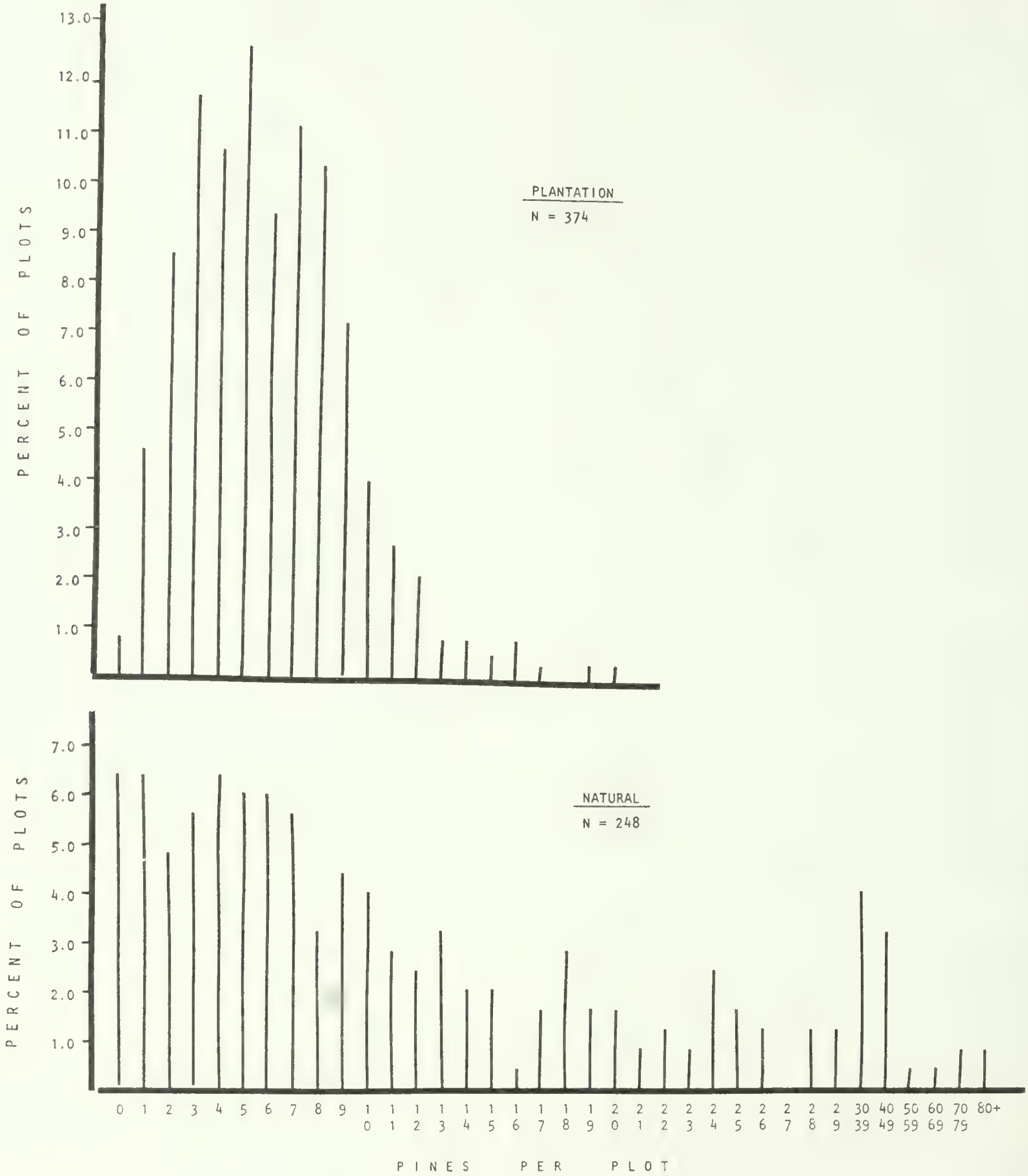

Figure 1.--Frequency distribution of number of loblolly seedlings on 0.004 ha plots in natural stands and plantations of loblolly pine in five South Carolina Piedmont counties.

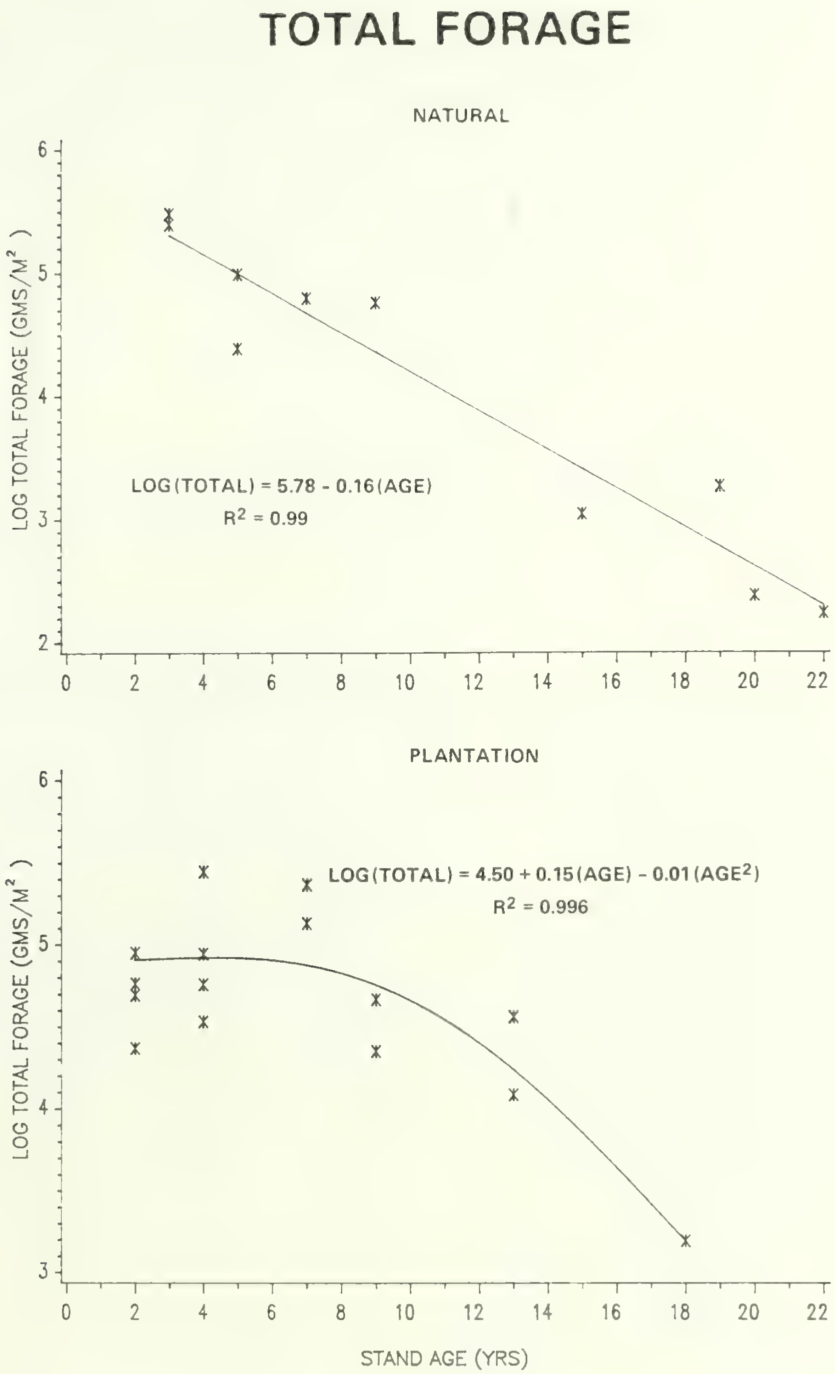

Figure 2.--Relationship between total forage component and stand age in natural stands and plantations of loblolly pine in five South Carolina Piedmont counties.

Table 1.--Models to describe the relationship between selected habitat components and stand age in natural stands and plantations of loblolly pine in five western Piedmont counties of South Carolina.

Parameter	Model	r^2
	Natural regeneration	
Forage		
Herbaceous	$\mathrm{Log(HERB)} = 4.35 - 0.25(\mathrm{AGE})$	0.92
Vine	$\mathrm{Log(VINE)} = 4.46 - 0.20(\mathrm{AGE})$	0.91
Grass	$\mathrm{Log(GRASS)} = 0.43 + 0.29(\mathrm{AGE}) - 0.02(\mathrm{AGE}^2)$	0.97
Woody	$\mathrm{Log(WOODY)} = 4.56 + 0.11(\mathrm{AGE})$	0.98
	Plantation	
Forage		
Herbaceous	$\mathrm{Log(HERB)} = 3.96 - 0.05(\mathrm{AGE}) - 0.005(\mathrm{AGE}^2)$	0.97
Vine	$\mathrm{Log(VINE)} = 1.44 + 0.38(\mathrm{AGE}) - 0.02(\mathrm{AGE}^2)$	0.94
Grass	$\mathrm{Log(GRASS)} = 2.76 + 0.25(\mathrm{AGE}) - 0.02(\mathrm{AGE}^2)$	0.97
Woody	$\mathrm{Log(WOODY)} = 2.49 + 0.33(\mathrm{AGE}) - 0.02(\mathrm{AGE}^2)$	0.97

DISCUSSION

The logarithm decline in forage weight between age 3 to 22 years in natural stands resulted from the shading of intolerant early-successional species by the developing pine regeneration. The two youngest stands (age 3) were cut in September 1978 and in February 1980, but were not burned until late-September or early-October 1982. The seedbed had become overgrown with vegetation. Since fire is a random process, the entire seedbed was not uniformly burned. Competing vegetation can cause seedbed conditions to deteriorate rapidly, reducing the germination rate of loblolly seed (Trousdell 1950, 1954). Pine seed fall was also random, resulting in dense clumps of seedlings. The youngest natural stands were probably supporting a near maximum amount of forage at the time of seedfall. Forage decreased rapidly as crown closure within and between clumps occurred. Amounts of forage components have been shown to be inversely related to stand characteristics that increase with age, such as basal area and dbh (Hurst et al. 1979).

The peak in forage development in plantations occurs prior to the time of canopy closure. While the canopy takes several years to close completely, light penetration to the ground is sufficiently reduced to suppress the development of understory vegetation. Thus, the decline in total forage weight after age 6. Others have suggested that unthinned pine stands provide forage for deer only until crown closure occurs, about 8 to 10 years after stand establishment (Blair 1976, Blair and Enghardt 1976, Halls 1970, 1973). Highest amounts of forage biomass in our study occurred about the same time as in other studies (Hurst and Warren 1980).

Table 2.--Parameter estimates (SE) for quadratic models of forage relationships to stand age.

Variable	Regeneration Method	Parameter Maximum value	Parameter Stand age (yrs)
Woody forage (gms/m^2)	P[1]	44.25	7.9 (1.0)
Vine forage (gms/m^2)	P	30.09	10.4 (1.3)
Grass forage (gms/m^2)	N	29.34	6.4 (1.6)
	P	31.88	5.5 (1.0)
Total forage (gms/m^2)	P	139.41	6.0 (1.1)

[1] P = plantation, N = natural stand.

SUMMARY

In natural stands, three of four forage components and total forage were adequately described by a log-linear model. Grass forage was described by a quadratic equation. In plantations, a quadratic model provided the best fit for the logarithm of each component and total forage. Timing of site preparation, seedfall patterns and pine density were thought to strongly influence the response of forage to stand age. These data can be used by wildlife managers to schedule thinnings which will open the pine canopy and improve deer habitat by stimulating forage production.

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Table 3.--Statistics for lack-of-fit test of linear and quadratic models to several habitat variables and stand age in natural stands and plantations of loblolly pine in 5 western Piedmont counteis of South Carolina.

Variable[1]	Natural Model	Natural d.f.	Natural F-ratio	Plantation Model	Plantation d.f.	Plantation F-ratio
Woody forage	Linear	6,2	0.34	Quadratic	3,9	1.77
Vine forage	Linear	6,2	0.79	Quadratic	3,9	0.38
Grass forage	Quadratic	5,2	1.60	Quadratic	3,9	2.18
Herbaceous forage	Linear	6,2	22.78*	Quadratic	3,9	1.54
Total forage	Linear	6,2	1.51	Quadratic	3,9	1.54

*Evidence that models are not adequate (P 0.05)

[1] All variables were log transformed before analysis.

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